UNIVERSITY OF
ILLINOIS LIBRARY
AT URBANA-CHAMPAIGN
BOOKSTACKS

CENTRAL CIRCULATION BOOKSTACKS
The person charging this material is responsible for its renewal or its return to the library from which it was borrowed on or before the **Latest Date** stamped below. **The Minimum Fee for each Lost Book is $50.00.**

Theft, mutilation, and underlining of books are reasons for disciplinary action and may result in dismissal from the University.

TO RENEW CALL TELEPHONE CENTER, 333-8400

UNIVERSITY OF ILLINOIS LIBRARY AT URBANA-CHAMPAIGN

MAY 04 1994

When renewing by phone, write new due date below previous due date. L162

Digitized by the Internet Archive
in 2016

https://archive.org/details/philosophicaltra1631roya

PHILOSOPHICAL
TRANSACTIONS

OF THE

ROYAL SOCIETY

OF

LONDON.

FOR THE YEAR MDCCCLXXIII.

VOL. 163.

LONDON:
PRINTED BY TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET
MDCCCLXXIV.

506
RO
v 163

CONTENTS

OF VOL. 163.

PART I.

I. *The Diurnal Variations of the Wind and Barometric Pressure at Bombay. By* F. CHAMBERS. *Communicated by* CHARLES CHAMBERS, *F.R.S., Director of the Colaba Observatory, Bombay* . . . . page 1

I*. *On the Osteology of the* Hyopotamidæ. *By Dr.* W. KOWALEVSKY. *Communicated by Professor* HUXLEY, *Sec. R.S.* 19

II. THE BAKERIAN LECTURE.—*On the Structure and Development of the Skull in the Salmon* (Salmo salar, *L.*). *By* WILLIAM KITCHEN PARKER, *F.R.S.* . . . 95

III. *Volcanic Energy: an attempt to develop its true Origin and Cosmical Relations. By* ROBERT MALLET, *A.M., C.E., M.R.I.A., F.R.S.* 147

IV. *On Curvature and Orthogonal Surfaces. By* A. CAYLEY, *LL.D., F.R.S., Sadlerian Professor of Mathematics in the University of Cambridge* 229

V. *Researches in Spectrum-Analysis in connexion with the Spectrum of the Sun. By* J. NORMAN LOCKYER, *F.R.S.* 253

VI. *Researches on the Atomic Weight of Thallium. By* WILLIAM CROOKES, *F.R.S., &c.* 277

VII. *Magnetical Observations in the Britannia and Conway Tubular Iron Bridges. By Sir* GEORGE BIDDELL AIRY, *K.C.B., P.R.S., Astronomer Royal* 331

VIII. *Magnetic Survey of Belgium in* 1871. *By the Rev.* STEPHEN J. PERRY. *Communicated by General Sir* EDWARD SABINE, *K.C.B., F.R.S.* 341

IX. *On the Union of Ammonia Nitrate with Ammonia. By* EDWARD DIVERS, *M.D. Communicated by* Professor ODLING, *M.B., F.R.S.* 359

X. *On the Organization of the Fossil Plants of the Coal-measures.*—Part IV. Dictyoxylon, Lyginodendron, *and* Heterangium. *By* W. C. WILLIAMSON, *F.R.S., Professor of Natural History in Owens College, Manchester* 377

55693

XI. *Determination of the Number of Electrostatic Units in the Electromagnetic Unit made in the Physical Laboratory of Glasgow University. By* Dugald M‘Kichan, *M.A. Communicated by Sir* William Thomson, *F.R.S. &c.* . . page 409

XII. *On the Minute Structure of the Leg-muscles of the Water-beetle. By* Edward Albert Schäfer. *Communicated by Dr.* Sharpey, *V.P.R.S.* 429

PART II.

XIII. *Results of the Comparisons of the Standards of Length of England, Austria, Spain, United States, Cape of Good Hope, and of a second Russian Standard, made at the Ordnance Survey Office, Southampton. By Lieutenant-Colonel* A. R. Clarke, *C.B., R.E., F.R.S., &c., under the direction of Major-General Sir* Henry James, *R.E., F.R.S., &c., Director-General of the Ordnance Survey. With a Preface and Notes on the Greek and Egyptian Measures of Length by Sir* Henry James 445

XIV. *Report on the Exploration of Brixham Cave, conducted by a Committee of the Geological Society, and under the superintendence of* Wm. Pengelly, *Esq., F.R.S., aided by a local Committee; with Descriptions of the Animal Remains by* George Busk, *Esq., F.R.S., and of the Flint Implements by* John Evans, *Esq., F.R.S. By* Joseph Prestwich, *F.R.S., F.G.S., &c., Reporter* 471

XV. *On a new Locality of Amblygonite, and on Montebrasite, a new Hydrated Aluminium and Lithium Phosphate. By* M. A. O. Des Cloizeaux, *Member of the Institute of France. Communicated by Professor* W. H. Miller, *Foreign Secretary R.S.* 573

XVI. The Bakerian Lecture.—*On the Radiation of Heat from the Moon, the Law of its Absorption by our Atmosphere, and of its Variation in Amount with her Phases. By the* Earl of Rosse, *B.A., D.C.L., F.R.S.* 587

XVII. *On a new Genus of Amphipod Crustaceans. By* Rudolph von Willemöes-Suhm, *Ph.D., Naturalist to the ‘Challenger’ Exploring-Expedition. Communicated by Dr.* Wyville Thomson, *F.R.S.* 629

XVIII. *Researches in Spectrum-Analysis in connexion with the Spectrum of the Sun.—* No. II. *By* J. Norman Lockyer, *F.R.S.* 639

Index 659

LIST OF ILLUSTRATIONS.

Plates I. to VIII.—Mr. W. K. Parker on the Structure and Development of the Skull in the Salmon.

Plates IX. and X.—Mr. Robert Mallet on Volcanic Energy.

Plates XI. to XIII.—Mr. J. Norman Lockyer on Spectrum-Analysis in connexion with the Spectrum of the Sun.

Plates XIV. to XVII.—Mr. W. Crookes on the Atomic Weight of Thallium.

Plate XVIII.—The Astronomer Royal—Magnetical Observations in the Britannia and Conway Tubular Iron Bridges.

Plates XIX. to XXI.—The Rev. Stephen J. Perry—Magnetic Survey of Belgium in 1871.

Plates XXII. to XXXI.—Professor W. C. Williamson on the Organization of the Fossil Plants of the Coal-measures.

Plate XXXII.—Mr. Dugald M'Kichan—Determination of the Number of Electrostatic Units in the Electromagnetic Unit.

Plate XXXIII.—Mr. E. A. Schäfer on the Minute Structure of the Leg-muscles of the Water-beetle.

Plate XXXIV.—Mr. F. Chambers on the Diurnal Variations of the Wind and Barometric Pressure at Bombay.

Plates XXXV. to XL.—Dr. W. Kowalevsky on the Osteology of the *Hyopotamidæ*.

Plates XLI. to XLVII.—Report on the Exploration of Brixham Cave.

Plate XLVIII.—The Earl of Rosse on the Radiation of Heat from the Moon.

Plates XLIX. & L.—Dr. Rudolph von Willemöes-Suhm on a new Genus of Amphipod Crustaceans.

Plates LI. & LII.—Mr. J. Norman Lockyer on Spectrum-Analysis in connexion with the Spectrum of the Sun.

LIST OF ILLUSTRATIONS.

Plates I. to VIII.—Mr. W. K. Parker on the Structure and Development of the Skull in the Salmon.

Plates IX. and X.—Mr. Robert Mallet on Volcanic Energy.

Plates XI. to XIII.—Mr. J. Norman Lockyer on Spectrum-Analysis in connexion with the Spectrum of the Sun.

Plates XIV. to XVII.—Mr. W. Crookes on the Atomic Weight of Thallium.

Plate XVIII.—The Astronomer Royal—Magnetical Observations in the Britannia and Conway Tubular Iron Bridges.

Plates XIX. to XXI.—The Rev. Stephen J. Perry—Magnetic Survey of Belgium in 1871.

Plates XXII. to XXXI.—Professor W. C. Williamson on the Organization of the Fossil Plants of the Coal-measures.

Plate XXXII.—Mr. Dugald M'Kichan—Determination of the Number of Electrostatic Units in the Electromagnetic Unit.

Plate XXXIII.—Mr. E. A. Schäfer on the Minute Structure of the Leg-muscles of the Water-beetle.

Plate XXXIV.—Mr. F. Chambers on the Diurnal Variations of the Wind and Barometric Pressure at Bombay.

Plate XXXV. to XL.—Dr. W. Kowalevsky on the Osteology of the *Hyopotamidæ*.

THE ROYAL SOCIETY.

30th November 1873.

THE ROYAL SOCIETY. Nov. 30, 1873.

Her Sacred Majesty QUEEN VICTORIA, Patron.

Date of Election.	
1863. Feb. 12.	HIS ROYAL HIGHNESS THE PRINCE OF WALES, K.G.
1865. Apr. 27.	HIS ROYAL HIGHNESS LOUIS PHILIPPE D'ORLÉANS, COUNT OF PARIS.
1871. Nov. 23.	HIS MAJESTY PEDRO II. EMPEROR OF BRAZIL.

THE COUNCIL

OF

THE ROYAL SOCIETY.

JOSEPH DALTON HOOKER, C.B., M.D., D.C.L., LL.D.—PRESIDENT.

WILLIAM SPOTTISWOODE, M.A., LL.D.—TREASURER AND VICE-PRESIDENT.
PROF. GEORGE GABRIEL STOKES, M.A., D.C.L., LL.D.—SECRETARY.
PROF. THOMAS HENRY HUXLEY, LL.D.—SECRETARY.
PROF. ALEXANDER WILLIAM WILLIAMSON, PH.D.—FOREIGN SECRETARY.
SIR GEORGE BIDDELL AIRY, K.C.B., M.A.—VICE-PRESIDENT.
SIR B. C. BRODIE, BART., M.A., D.C.L.
PROF. ARTHUR CAYLEY, LL.D.
JOHN EVANS, SEC. G.S., F.S.A.
DANIEL HANBURY, TREAS. L.S.
NEVIL STORY MASKELYNE, M.A.
PROF. JAMES CLERK MAXWELL, M.A.
C. WATKINS MERRIFIELD, HON. SEC. I.N.A.
JOSEPH PRESTWICH, V.P.G.S.
ANDREW CROMBIE RAMSAY, LL.D.—VICE-PRESIDENT.
REAR-ADMIRAL G. H. RICHARDS, C.B.
PROF. GEORGE ROLLESTON, M.D., M.A.
PROF. J. S. BURDON SANDERSON, M.D.
WILLIAM SHARPEY, M.D., LL.D.—VICE-PRESIDENT.
FRANCIS SIBSON, M.D.
MAJOR-GEN. R. STRACHEY, R.E., C.S.I.—VICE-PRESIDENT.

⁂ *This Council will continue till November* 30, 1874.

Assistant-Secretary and Librarian.

WALTER WHITE.

Clerk.

HENRY B. WHEATLEY.

Omissions having occasionally occurred in the Annual List of Deceased Fellows, as announced from the Chair at the Anniversary Meeting of the Royal Society, it is requested that any information on that subject, as also Notice of Changes of Residence, be addressed to the Assistant Secretary.

FELLOWS OF THE SOCIETY.

NOVEMBER 30, 1873.

(C) prefixed to a name indicates that the Fellow has received a Copley Medal.
(R) ... ... Royal Medal.
(Rm) ... ... Rumford Medal.
(P) ... ... has contributed a Paper to the Philosophical Transactions.
(†) ... ... is liable to an annual payment of £4.

Date of Election.		
1860. June 7.	P.	† Abel, Frederick Augustus, Esq., Treas. C.S. Director of the Chemical Establishment of the War Department. *Royal Arsenal, Woolwich.* S.E.
1847. Jan. 21.		Acland, Henry Wentworth Dyke, A.M. M.D. LL.D. (Cantab.) F.R.G.S., Coll. Reg. Med. Soc., Hon. Student of Ch. Ch., Radcliffe Librarian and Regius Professor of Medicine in the University of Oxford. *Broad-street, Oxford.*
1872. June 6.		† Adams, Andrew Leith, M.A. M.B. F.G.S. Surgeon-Major. 30 *Bloomfield-street, Westbourne-terrace.* W.
1849. June 7.	C.P.	Adams, John Couch, Esq., LL.D. (Dubl.) V.P.R.A.S. F.C.P.S., Director of the Observatory and Lowndsean Professor of Astronomy and Geometry in the University of Cambridge, Inst. Fr. (Acad. Sci.) Par. Corr., Soc. Reg. Sci. Gott. Corresp. et Acad. Amer. Art. et Sc. Socius. *The Observatory, Cambridge.*
1872. June 6.		† Adams, William Grylls, M.A. F.G.S. F.C.P.S. Professor of Natural Philosophy and Astronomy in King's College, London. 9 *Notting-hill-square.* W.
1846. Jan. 29.	P.	† Addison, William, M.D. F.L.S. Coll. Reg. Med. Socius. 48 *Norfolk-square, Brighton.*
1836. Jan. 21.	C.R. P.	Airy, Sir George Biddell, K.C.B. M.A. D.C.L. (Oxon.) LL.D. (Cantab.) LL.D. (Edin.) Astronomer Royal.—VICE-PRESIDENT.—V.P.R.A.S.—Hon. Mem. R.S.E. R.I.A. F.C.P.S., Trust. Brit. Mus. Ord. Boruss. "*Pour le Mérite*" Eq., Inst. Fr. (Acad. Sc.) Paris., Acadd. Imp. Sc. Petrop., et Reg. Sc. Berol. Corresp., Acadd. Sc. Lit. Panorm., Holm. et Monach. Socc. Reg., Sc. Hafn., Acad. Amer. Art. et Sc. Bost. Nat. Inst. Washington Socius. *The Royal Observatory, Greenwich.* S.E.
1873. June 12.		† Aitken, William, M.D. (Edin.) M.R.C.S.E. Professor of Pathology in the Army Medical School, Netley. *Park Villa, Woolston, Southampton.*
1841. June 17.		† Alderson, Sir James, Knt., M.A. M.D. D.C.L. (Oxon.) Coll. Reg. Med. Socius, Consulting Physician to St. Mary's Hospital. 17 *Berkeley-square.* W.
1854. June 1.	R.P.	Allman, George James, M.D. F.R.S.E. M.R.I.A. Emeritus Professor of Natural History in the University of Edinburgh. 21 *Marlborough-road, St. John's Wood,* N.W.; *and Athenæum Club.* S.W.
1849. June 7.	R.P.	Andrews, Thomas, M.D. LL.D. (Edin.) Hon. F.R.S.E. M.R.I.A. F.C.S. Vice-President and Professor of Chemistry in Queen's College, Belfast. *Queen's College, Belfast.*

Date of Election.		
1834. Apr. 10.		Ansell, Charles, Esq., F.S.A. 7 *Eastern-terrace, Brighton.*
1844. Jan. 11.		† Ansted, David Thomas, Esq., M.A. (Cantab.) F.G.S. F.R.G.S. F.S.A. F.C.P.S., Hon. Mem. R.I.B.A., Ord. Hellen. "du Sauveur" Eq., Soc. Reg. Sci. Lond. Corr. Mem. 8 *Duke-street, Adelphi,* W.C.; *and Melton, Suffolk.*
1853. June 2.		Apjohn, James, M.D. M.R.I.A. F.C.S. Professor of Chemistry, Trinity College, Dublin. 32 *Baggot-street, Dublin.*
1851. June 19.		† Argyll, George John Douglas Campbell, Duke of, K.T. D.C.L. (Oxon.) Trust. Brit. Mus. Hon. V.P.R.S.Edin. Pres.G.S. *Argyll Lodge, Kensington,* W.; *and Inverary Castle, Argyleshire.*
1873. June 12.		† Armstrong, Sir Alexander, M.D. LL.D. (Dubl.) K.C.B. F.R.G.S. Director-General of the Medical Department of the Navy. Hon. Physician to the Queen and to H.R.H. The Prince of Wales. *The Admiralty, New-street, Spring-gardens.* S.W.
1846. May 7.		Armstrong, Sir William George, C.B. D.C.L. (Oxon.) *Newcastle-upon-Tyne.*
1843. May 25.	Rm.	† Arnott, James Moncrieff, Esq., Surgeon Extraordinary to the Queen. *Chapelhouse, Kingskettle, Fifeshire.*
1838. Jan. 25.		† Arnott, Neil, M.D. F.G.S. Physician Extraordinary to the Queen. 2 *Cumberland-terrace.* N.W.
1851. June 5.		Babington, Charles Cardale, Esq., M.A. F.L.S. F.G.S. M.C.P.S. Professor of Botany. 5 *Brookside, Cambridge.*
1847. Jan. 7.		† Back, Sir George, Knt., Admiral, D.C.L. V.P.R.G.S. Soc. Geog. Par., et Soc. Hist. Nat. Montreal Corresp. 109 *Gloucester-place, Portman-square.* W.
1869. June 3.		† Baker, Sir Samuel White, M.A. F.R.G.S.
1856. June 5.		Balfour, John Hutton, M.D. M.A. Sec. R.S. Edin. F.L.S. Professor of Botany in the University of Edinburgh. 27 *Inverleith-row, Edinburgh.*
1858. June 3.		† Balfour, Thomas Graham, M.D. Coll. Reg. Med. Socius, Deputy Inspector-General of Hospitals. *Royal Victoria Hospital, Netley.*
1868. June 4.		† Ball, John, Esq., M.A. F.L.S. M.R.I.A. 10 *Southwell-gardens, South Kensington,* S.W.; *and Athenæum Club.*
1873. June 12.		† Ball, Robert Stawell, Esq., LL.D. M.R.I.A. Professor of Applied Mathematics and Mechanism, Royal College of Science, Ireland. 47 *Wellington-place, Upper Leeson-street, Dublin.*
1864. June 2.		† Barkly, Sir Henry, K.C.B. Governor of Cape Colony and Dependencies. *Cape of Good Hope.*
1845. Nov. 20.	P.	Barlow, Peter William, Esq., F.G.S. 8 *Eliott-place, Blackheath,* S.E.; *and* 26 *Great George-street.* S.W.
1850. June 6.	P.	Barlow, W. H., Esq. *High Combe, Old Charlton.* S.E.
1844. Dec. 12.		Barrow, John, Esq., F.S.A. 17 *Hanover-terrace, Regent's-park.* N.W.
1868. June 4.	P.	Bastian, Henry Charlton, M.D. M.A. F.L.S. Professor of Pathological Anatomy at University College Hospital. 81 *Avenue-road, Regent's-park,* N.W.; *and* 20 *Queen-Anne-street.* W.
1861. June 6.	P.	Bate, Charles Spence, Esq., F.L.S. 8 *Mulgrave-place, Plymouth.*
1838. Feb. 8.		† Bateman, James, Esq., M.A. F.L.S. 9 *Hyde-park-gate South,* W.; *and Biddulph Grange, Congleton.*
1860. June 7.		† Bateman, John Frederic, Esq., F.G.S. 16 *Great George-street.* S.W.

Date of Election.			
1857. June 11.	P.		Beale, Lionel Smith, M.D. Coll. Reg. Med. Socius, Professor of Physiology and of General and Morbid Anatomy in King's College, London. 61 *Grosvenor-street.* W.
1827. Nov. 15.			Beamish, North Ludlow, Lieut.-Col., K.H. *Ann Mount, New Glanmire, Co. Cork.*
1835. June 4.		†	Beaumont, Edward Blackett, Esq., F.R.A.S. 33 *Norland-square,* W.; *and Travellers' Club.* S.W.
1851. June 5.	R. P.		Beck, Thomas Snow, M.D. 7 *Portland-place.* W.
1859. June 9.		†	Beckles, Samuel Husbands, Esq., F.G.S. 9 *Grand Parade, St. Leonard's.*
1873. June 12.		†	Beddoe, John, M.D. B.A. Soc. Anthrop. Berol. Corresp. et Soc. Anthrop. Par. Soc. Extr. 2 *Lansdown-place, Clifton, Bristol.*
1835. Feb. 5.		†	Beetham, Albert William, Esq., Recorder of Dartmouth. 11 *South-square, Gray's Inn,* W.C.; *and Uplyme, Devonshire.*
1828. Jan. 10.	P.		Bell, Thomas, Esq., F.L.S. F.G.S. Socc. Hist. Nat. et Philomath. Paris., Acad. Sc. Philad. et Soc. Hist. Nat. Bost. Corresp., Prof. of Zoology, King's College, London. *The Wakes, Selborne, near Alton, Hants.*
1834. Dec. 18.		†	Bellamy, Rev. James William, B.D. *Sellindge Vicarage, Hythe, Kent.*
1860. Mar. 22.		†	Belper, Edward Lord, M.A. F.G.S. F.Z.S. Pres. Univ. Coll. London. 88 *Eaton-square,* S.W.; *and Kingston-hall, Derby.*
1841. Dec. 16.		†	Bennett, John Joseph, Esq., V.P.L.S. *Sandrock, Maresfield, Sussex.*
1862. June 5.	R.	†	Bentham, George, Esq., President of the Linnean Society. 25 *Wilton-place.* S.W.
1871. June 8.			Besant, William Henry, Esq., M.A. Mathematical Lecturer at St. John's College, Cambridge. 4 *Benet-place, Cambridge.*
1869. June 3.		†	Bigsby, John Jeremiah, M.D. F.G.S. & R.G.S. 89 *Gloucester-place, Portman-square.* W.
1844. June 6.		†	Billing, Archibald, M.D. A.M. F.G.S., Coll. Reg. Med. Socius, Soc. Med. Nov. Ebor. Socius, Soc. Med.-Phys. Florent. et Dresd. Med.-Chir. Brux. Corresp. 6 *Grosvenor-gate.* W.
1856. June 5.	P.		Binney, Edward William, Esq., F.G.S. *Cheetham-hill, Manchester.*
1843. April 6.			Blake, Henry Wollaston, Esq., M.A. 8 *Devonshire-place, Portland-place.* W.
1831. Jan. 20.			Blake, William John, Esq., M.A. F.G.S. 25 *Portland-place.* W.
1841. Jan. 21.		†	Blakiston, Peyton, M.D. Coll. Reg. Med. Socius. 55 *Victoria-street, Westminster.* S.W.
1841. June 10.		†	Blore, Edward, Esq., LL.D. F.S.A. 4 *Manchester-square.* W.
1837. May 11.			Boase, Henry, M.D. F.G.S. *Seafield-house, Magdalen-place, Dundee.*
1840. Mar. 5.		†	Boileau, John Theophilus, Major-General, F.R.A.S. 31 *Ladbroke-square, Notting-hill.* W.
1846. Jan. 22.	P.	†	Booth, Rev. James, LL.D. F.R.A.S. F.R.G.S. *The Vicarage, Stone, near Aylesbury.*
1829. June 4.			Bosworth, Rev. Joseph, D.D. LL.D. F.S.A. M.R.I.A. Soc. Reg. Antiq. Septen. Hafn. Corresp., Socc. Reg. Sc. Norv., Dronth., et Gothob. Socius, Professor of Anglo-Saxon in the University of Oxford. *Carlton Lodge, Oxford.*
1863. Feb. 19.		†	Bouverie, Right Hon. Edward Pleydell. 44 *Wilton-crescent.* S.W.
1842. Nov. 17.	P.		Bowerbank, James Scott, Esq., LL.D. F.L.S. F.G.S. 2 *East Ascent, St. Leonard's.*
1841. Apr. 22.	R. P.		Bowman, William, Esq., F.R.C.S. 5 *Clifford-street.* W.
1858. June 3.		†	Boxer, Edward Mounier, Major-General, R.A. *Upton House, near Ryde.*

Date of Election.		
1873. June 12.		† Bramwell, Frederick Joseph, Esq., M.I.C.E. 37 *Great George-street, Westminster.* S.W.
1838. Nov. 22.		† Briggs, John, General, M.R.A.S. F.G.S. 2 *Tenterden-street,* W.; *and Bridge Lodge, Hurstpierpoint, Sussex.*
1862. June 5.		† Bristow, Henry William, Esq., F.G.S., Director of the Geological Survey of England and Wales. *Geological Survey Office, Jermyn-street.* S.W.
1849. June 7.	R. P.	Brodie, Sir Benjamin Collins, Bart., M.A. D.C.L. (Oxon.) V.P.C.S. *Brockham Warren, Reigate.*
1847. Mar. 4.	P.	Brooke, Charles, Esq., M.A. F.R.C.S., Surgeon to the Westminster Hospital. 16 *Fitzroy-square.* W.
1843. Mar. 16.		† Brooke, Sir William Brooke O'Shaughnessy, M.D. 55 *Parliament-street.* S.W.
1853. June 2.		Broun, John Allan, Esq. 4 *Abercorn-place, St. John's-wood.* N.W.
1860. June 7.		† Brown-Séquard, Charles Edouard, M.D. Coll. Reg. Med. Socius.
1833. June 20.		Buccleuch, Walter Francis Montagu-Douglas Scott, Duke of, K.G. D.C.L. F.L.S. *Whitehall-gardens,* S.W.; *and Dalkeith House, near Edinburgh.*
1866. June 7.		† Bucknill, John Charles, M.D. Chancery Visitor of Lunatics, Coll. Reg. Med. Socius. Soc. Psychol. Par. Soc. Honor. *Hillmorton-hall, near Rugby.*
1857. June 11.	P.	Buckton, George Bowdler, Esq., F.C.S. F.L.S. *Weycombe, Haslemere, Surrey.*
1836. Jan. 21.		† Budd, George, M.D. Coll. Reg. Med. Socius. *Ashleigh, Barnstaple, Devonshire.*
1871. June 8.		† Budd, William, M.D. (Edin.). *The Manor House, Clifton, Bristol.*
1851. June 5.		Bunbury, Sir Charles James Fox, Bart., F.G.S. F.L.S. *Barton-hall, Bury St. Edmunds.*
1838. May 3.		† Burnet, Rev. Thomas, D.D. 24 *Lower Rock Gardens, Brighton.*
1847. Apr. 22.		† Burrows, George, M.D. D.C.L. (Oxon.) President of the Royal College of Physicians, Trust. Brit. Mus. Physician in Ordinary to the Queen. Consulting Physician to St. Bartholomew's Hospital. President of the Medical Council. 18 *Cavendish-square.* W.
1836. Mar. 17.		Burt, Major T. Seymour, M.R.A.S. *Pippbrook House, Dorking, Surrey.*
1832. Dec. 6.		Burton, Decimus, Esq., F.S.A. F.G.S. 1 *Gloucester-houses, Gloucester-crescent, Bishop's-road,* W.; *and St. Leonard's.*
1850. June 6.	R.	Busk, George, Esq., V.P.L.S. F.R.C.S. F.G.S. 32 *Harley-street.* W.
1822. Mar. 21.		Butter, John, M.D. F.L.S. *Windsor-villas, Plymouth*; *and Corringdon-hall, South-Brent, Devonshire.*
1837. Jan. 19.		Cabbell, Benjamin Bond, Esq., M.A. F.S.A. F.G.S. 1 *Brick-court, Temple,* E.C.; *and* 45 *Portland-place.* W.
1862. Nov. 20.		† Caithness, James Sinclair, Earl of. 34 *Hill-street, Berkeley-square,* W.; *Stagenhoe Park, Herts; and Barrogill Castle, Caithness.*
1871. June 8.	P.	Callender, George William, Esq., F.R.C.S. Surgeon to St. Bartholomew's Hospital. 47 *Queen-Anne-street.* W.
1873. June 12.		† Calver, Edward Killwick, Capt. R.N. Admiralty Surveyor, Assoc. Inst. C.E. 16 *Roker-terrace, Sunderland.*
1868. June 4.		† Cameron, John, Lieut.-Colonel R.E. C.B. *Ordnance Survey Office, Southampton.*
1859. Jan. 27.		† Canterbury, His Grace Archibald Campbell Tait, Lord Archbishop of, D.D. D.C.L. Trust. Brit. Mus. *The Palace, Lambeth,* S.W.; *and Addington Park, Croydon.*

Date of Election.			
1844. Feb. 1.	R. P.		Carpenter, William Benjamin, M.D. LL.D. F.G.S. F.L.S. Hon. F.C.P.S. Registrar of the University of London, Inst. Fr. (Acad. Sci.) Soc. Biol. Soc. Philomat. Paris, et Soc. Phil. Amer. Philad. Corr. Mem. 56 *Regent's-park Road.* N.W.
1860. June 7.			Carrington, Richard Christopher, Esq., F.R.A.S. F.C.P.S. *Churt, near Farnham.*
1871. June 8.		†	Carruthers, William, Esq., F.L.S. F.G.S. Keeper of the Botanical Department, British Museum. 25 *Wellington-street, Islington,* N.; *and British Museum.* W.C.
1859. June 9.	R.		Carter, Henry John, Esq., Surgeon-Major H.M. Bombay Army, H.M.R.A.S. (Bombay). *The Cottage, Budleigh-Salterton, Devon.*
1852. June 3.	R. P.		Cayley, Arthur, Esq., P.R.A.S. LL.D. (Dubl.) Sadlerian Professor of Mathematics in the University of Cambridge, Inst. Fr. (Acad. Sci.) Par. Acad. Reg. Berol. et Soc. Reg. Sci. Gött. Corresp. *Garden House, Cambridge.*
1848. June 9.	P.	†	Challis, Rev. James, F.R.A.S. Plumian Professor of Astronomy in the University of Cambridge. 2 *Trumpington-street, Cambridge.*
1869. June 3.	P.		Chambers, Charles, Esq., Superintendent of the Colaba Observatory, Bombay. *Bombay.*
1842. May 26.			Chapman, Thomas, Esq., F.S.A. 25 *Bryanston-square,* W.; *and Whitby.*
1845. June 19.			Chelmsford, Frederick, Lord, D.C.L. 7 *Eaton-square.* S.W.
1873. Jan. 16.		†	Childers, Right Hon. Hugh Culling Eardley, F.R.G.S. 17 *Prince's-gardens; and Athenæum Club.* S.W.
1847. Mar. 18.	P.		Christie, James Robert, Esq. *Arundel House, South Norwood-park.* S.E.
1872. June 6.		†	Clark, Frederick Le Gros, Esq., F.R.C.S. 14 *St. Thomas's-street, Borough,* S.E.; *and The Thorns, Sevenoaks, Kent.*
1862. June 5.	P.	†	Clarke, Alex. Ross, Lieut.-Colonel R.E. C.B. Hon. F.C.P.S. Acad. Imp. Sci. Petrop. Mem. Corr. *Ordnance Survey Office, Southampton.*
1854. June 1.	R. P.	†	Clarke, Jacob Lockhart, M.D. Coll. Reg. Med. Soc. F.K.Q.C.P.Dubl. 64 *Harley-street.* W.
1872. June 6.	P.		Cleland, John, M.D. Professor of Anatomy and Physiology in Queen's College, Galway. *Vicarscroft, Galway.*
1848. June 9.	P.	†	Clerk, Henry, Lieut.-Col. R.A. 3 *Hobart-place, Eaton-square.* S.W.
1868. June 4.			Clifton, Robert Bellamy, Esq., M.A. (Cantab. et Oxon.), F.R.A.S. Professor of Experimental Philosophy in the University of Oxford, Soc. Lit. Phil. Manc. Soc. Honor. *Portland Lodge, Park Town, Oxford.*
1864. June 2.		†	Cobbold, T. Spencer, M.D. F.L.S. Professor at the Royal Veterinary College, and Emeritus Swiney Lecturer on Geology, British Museum, Acad. Sci. Nat. Philad. Corr. 42 *Harley-street,* W.; *and* 74 *Portsdown-road, Maida-hill.* W.
1865. June 1.			Cockle, The Hon. Sir James, M.A. F.R.A.S. & C.P.S. Chief-Justice of Queensland. *Brisbane, Queensland, Australia.*
1863. June 4.			Cooke, Edward William, Esq., R.A. F.L.S. Z.S. G.S. & R.G.S. Accad. Bell. Art. Venet. Socius. *Glen Andred, Groombridge, Sussex; and Athenæum Club.* S.W.
1836. May 5.		†	Cox, William Sands, Esq. *Dosthill Hall, Wilnecote, Tamworth.*
1868. June 4.	P.	†	Crofton, Morgan William, Esq., B.A. Professor of Mathematics in the Royal Military Academy, Woolwich. *Woolwich.* S.E.

Date of Election.		
1863. June 4.	P.	† Crookes, William, Esq., F.C.S. 20 *Mornington-road.* N.W.
1850. June 6.		† Curling, Thomas Blizard, Esq., F.R.C.S. Consulting Surgeon to the London Hospital. 39 *Grosvenor-street.* W.
1858. June 3.	P.	Currey, Frederick, Esq., M.A. Sec.L.S. 3 *New-square, Lincoln's-inn.* W.C.
1841. May 27.		Cursetjee, Ardaseer, Esq. *Lowjee House, Marsh Gate, Richmond,* S.W.; *and Bombay.*
1834. Jan. 29.	C. R.P.	Darwin, Charles, Esq., M.A. F.G.S. F.L.S. Hon. F.R.S.E. & M.R.I.A. Ord. Boruss. "*Pour le Mérite*" Eq., Acadd. Imp. Reg. Sci. Vindob. Reg. Sci. Brux. et Soc. Asiat. Beng. Corresp. Acadd. Imp. Sci. Petrop. Reg. Sci. Berol. et Holm. Soc. Reg. Sci. Upsal. Acad. Cæs. Nat.-Cur. Dresd. Soc. Sci. Neoc. et Acad. Nat. Sci. Philad. Soc. Honor. *Down, Beckenham, Kent.*
1857. June 11.	R.	† Davidson, Thomas, Esq., F.G.S. 8 *Denmark-terrace, Brighton.*
1822. Mar. 28.		Davis, Sir John Francis, Bart., K.C.B. *Athenæum Club,* S.W.; *and Hollywood, near Compton, Bristol.*
1868. June 4.	P.	† Davis, Joseph Barnard, M.D. F.S.A. V.P.A.S.L. Socc. Anthrop. Par. Amer. et Hisp. Amic. Nat. Moscov. et Art. et Doctr. Rheno-Traject. Adsoc. Extr. Acadd. Sci. Nat. Philad. Reg. Med. Taurin. Reg. Sci. Litt. et Art. Mutin. Phys.-Med.-Stat. Mediol. Reg. Pelorit. Messem. Reg. Valdarn. Reg. Physiocrit. Senæ, Reg. Scient. Med. Panorm. et Med. Chir. Ferrar. Socc. Batav. Phil. Exp. Rotterod. Batav. Art. et Scient. Ins. Jabad. et Med. Chir. Bonon. Soc. Corresp. *Shelton, Staffordshire.*
1867. June 6.		† Dawkins, W. Boyd, Esq., M.A. (Oxon.) F.G.S. *Birchview, Norman-road, Rusholme, Manchester.*
1862. June 5.		Dawson, John W., Esq., LL.D. M.A. F.G.S. Principal of M'Gill College, Montreal. *Montreal.*
1861. June 6.	P.	† Debus, Heinrich, Esq., Ph.D. V.P.C.S. Professor of Chemistry at the Royal Naval College, Greenwich, Lecturer on Chemistry at Guy's Hospital. *Guy's Hospital,* S.E.
1850. June 6.	R.P.	De La Rue, Warren, Esq., D.C.L. (Oxon.) Ph.D. V.P.C.S. V.P.R.A.S. Ord. SS^{rum} Maur. et Lazar. Ital. et Leg. Imp. Honor. Com. Ord. Imp. Bras. Rosae Eq. Soc. Photog. Edin. et Soc. pro Phys. indag. Berol. Soc. Honor. Acad. Imp. Sci. Petrop. Soc. Reg. Sci. Upsal Soc. Philom. Par. Soc. d'Agric. et de Commerce de Caen. et Soc. Imp. Sci. Nat. Carob. Mem. Corr. 73 *Portland-place,* W.; *and Reform Club.* S.W.
1861. June 6.	P.	De Morgan, Campbell, Esq., F.R.C.S. Surgeon and Lecturer on Physiology to Middlesex Hospital. 29 *Seymour-street, Portman-square.* W.
1839. Feb. 28.		† Denham, Sir Henry Mangles, Vice-Admiral. 21 *Carlton-road, Maida-vale,* W.; *and Athenæum and United Service Clubs.* S.W.
1859. Dec. 15.		Derby, Henry Edward Smith-Stanley, Earl, LL.D. M.A. 23 *St. James's-square,* S.W.; *and Knowsley-park, Prescott, Lancashire.*
1829. Dec. 10.		Devonshire, William, Duke of, K.G., M.A. D.C.L. F.G.S. Chancellor of the University of Cambridge. *Devonshire-house, Piccadilly,* W.; *and Chatsworth, Derbyshire.*
1836. Feb. 4.		† Drory, George William, Esq. 30 *Clement's-lane, Lombard-street.* E.C.
1855. Feb. 22.		Ducie, Henry John Reynolds-Moreton, Earl of, F.G.S. 17 *Portman-square.* W.
1865. Feb. 9.		Dufferin and Claneboye, Frederick Temple Blackwood, Earl, K.P. K.C.B. *Government House, Ottawa, Canada.*

Date of Election.			
1868. June 4.	P.	†	Duncan, Peter Martin, M.B. (Lond.) V.P.G.S. Professor of Geology in King's College, London, and Examiner in Geology in the University of London. 40 *Blessington-road, Lee.* S.E.
1863. June 4.		†	Eardley-Wilmot, Frederick Marow, Major-General R.A. 9 A *Victoria-road, Clapham-common.* S.W.
1851. June 5.			Eastwick, Edward Backhouse, Esq., C.B. M.R.A.S. F.S.A. 38 *Thurloe-square.* S.W.
1831. Feb. 10.	P.		Egerton, Sir Philip de Malpas Grey, Bart., V.P.G.S. Trust. Brit. Mus. 28 B *Albemarle-street,* W.; *and Oulton-park, Tarporley, Cheshire.*
1873. June 12.		†	Ellery, Robert Lewis John, Esq,, F.R.A.S. Government Astronomer, and Superintendent of the Geodetic Survey of the Colony of Victoria. *Melbourne, Victoria.*
1832. April 5.			Elliott, Rev. Charles Boileau, M.A. *Nice.*
1864. June 2.		†	Ellis, Alexander John, Esq., B.A. F.C.P.S. F.S.A. 25 *Argyll-road, Kensington.* W.
1841. Jan. 14.			Enderby, Charles, Esq., F.L.S. *Royal Institution.*
1829. Jan. 15.			Enniskillen, William Willoughby, Earl of, D.C.L. F.G.S. *Athenæum Club,* S.W.; *and Florence-court, Fermanagh, Ireland.*
1860. Nov. 22.		†	Erle, Rt. Hon. Sir William, Knt., D.C.L. *Bramshott Grange, Liphook, Hants.*
1869. June 3.	P.		Esson, William, Esq., M.A. F.C.S. F.R.A.S. *Merton College, and* 1 *Bradmore Road, Oxford.*
1871. June 8.		†	Etheridge, Robert, Esq., F.R.S.E. F.G.S. Demonstrator upon Palæontology Royal School of Mines, Palæontologist to the Geological Survey of Great Britain. 19 *Halsey-street, Cadogan-place, Chelsea,* S.W.; *and Royal School of Mines.*
1862. June 5.	P.	†	Evans, Frederick J. Owen, Staff Captain R.N., C.B. F.R.A.S. & G.S. 116 *Victoria-street, Westminster.* S.W.
1864. June 2.			Evans, John, Esq., Sec.G.S. F.S.A. A.I.C.E. Soc. d'Emulat. Abbav. et Soc. Arch. Luxumb. Mem. Corr. *Nash Mills, Hemel-Hempstead; and* 65 *Old Bailey.* E.C.
1850. June 6.	R.P.		Fairbairn, Sir William, Bart., LL.D. Inst. Fr. (Acad. Sci.) Par, et Acad. Reg. Taurin. Corresp. *Manchester.*
1855. June 7.	P.	†	Farr, William, M.D. D.C.L. Hon. F. Roy. Med. and Chir. Soc., Superintendent of the Statistical Department, General Register Office. Inst. Fr. (Acad. Mor. et Polit.) Corresp. *Southlands, Bromley, Kent; and Somerset-house.* W.C.
1866. June 7.		†	Farrar, Rev. Frederic William, M.A. D.D. (Cantab.) F.E.S. *The Lodge, Marlborough College, Marlborough.*
1839. May 2.	P.	†	Farre, Arthur, M.D. Coll. Reg. Med. Socius, Physician-Accoucheur to H.R.H. The Princess of Wales. 12 *Hertford-street.* W.
1863. June 4.		†	Fergusson, James, Esq., D.C.L. (Oxon.) F.R.A.S. R.G.S. R.I.B.A. 20 *Langham-place,* W.; *and Athenæum Club.* S.W.
1848. June 9.		†	Fergusson, Sir William, Bart., F.R.C.S. F.R.S.E. Serjeant-Surgeon in Ordinary to the Queen, Professor of Surgery in King's College. 16 *George-street, Hanover-square.* W.
1863. June 4.		†	Field, Frederick, Esq., F.R.S.E. M.R.I.A. F.C.S. *Hither Green Lodge, Lewisham,* S.E.
1855. June 7.			Fischer, William Lewis Ferdinand, Esq., F.C.P.S. Professor of Natural Philosophy, University of St. Andrews. *St. Andrews.*
1855. June 7.		†	Fletcher, Isaac, Esq., F.R.A.S. *Tarn-bank, Carlisle.*

Date of Election.			
1839. Mar. 21.			Fletcher, Thomas William, Esq., M.A. F.S.A. F.G.S. *Lawneswood-house, near Stourbridge.*
1864. June 2.	P.		Flower, William Henry, Esq., F.R.C.S. V.P.Z.S. F.L.S. Hunterian Professor of Comparative Anatomy, and Conservator of the Museum of the Royal College of Surgeons. *Royal College of Surgeons, Lincoln's Inn Fields.* W.C.
1858. June 3.			Forbes, David, Esq., Sec.G.S. F.C.S. 11 *York-place, Portman-square.* W.
1869. June 3.	P.		Foster, George Carey, Esq., B.A. F.C.S. Professor of Physics in University College, London. 12 *Hilldrop-road.* N.
1872. June 6.		†	Foster, Michael, M.D. Hon. M.A. (Cantab.) B.A. (Lond.) F.L.S. F.C.S. Prelector of Physiology in Trinity College, Cambridge, and Fullerian Professor of Physiology in the Royal Institution, London. *Trinity College, Cambridge.*
1848. June 9.	P.	†	Fox, Robert Were, Esq. *Falmouth.*
1872. June 6.		†	Fox, Wilson, M.D. Coll. Reg. Med. Soc. Physician Extraordinary to the Queen. Physician to University College Hospital. Holme Professor of Clinical Medicine at University College. 67 *Grosvenor-street.* W.
1853. June 2.	R. P.		Frankland, Edward, Esq., D.C.L. (Oxon.) Ph.D. (Marp.) Pres.C.S. Professor of Chemistry in the Royal School of Mines, Inst. Fr. (Acad. Sci.) Par. Corresp., Soc. Nat. Scrutat. Helvet., Acad. Reg. Monac. Socius, Soc. Lit. Phil. Manc., Soc. Chem. Lehigh Univ. U. S. et Soc. Nat. et Sanit. Dresd., Soc. Honor. *Royal College of Chemistry, South Kensington Museum,* S.W.; *and* 14 *Lancaster-gate, Hyde Park.* W.
1837. June 8.			Frere, George Edward, Esq. *Roydon-hall, Diss, Norfolk.*
1870. June 2.		†	Froude, William, Esq., M.A. M.I.C.E. and Inst. Mech. E. A.I.N.A. *Chelston Cross, Torquay.*
1859. June 9.			Galton, Douglas, Captain, C.B. F.G.S. F.L.S. 12 *Chester-st., Grosvenor-pl.* S.W.
1860. June 7.			Galton, Francis, Esq., M.A. F.G.S. V.P.R.G.S. 42 *Rutland-gate.* S.W.
1872. June 6.		†	Gamgee, Arthur, M.D. F.R.S. & F.R.C.P. Edin. Brackenbury Professor of Practical Physiology and Histology in Owens College, Manchester. *Manchester.*
1858. June 3.		†	Garrod, Alfred Baring, M.D. Coll. Reg. Med. Socius, Professor of Materia Medica in King's College, London, and Physician to the Hospital. 10 *Harley-street.* W.
1839. Mar. 21.			Gaskin, Rev. Thomas, M.A. F.R.A.S. *Jesus College, Cambridge.*
1840. April 9.	R. P.	†	Gassiot, John Peter, Esq., D.C.L. (Oxon.) F.C.S. *Clapham-common,* S.W.; *and St. John's House, Ryde, Isle of Wight.*
1865. June 1.		†	Geikie, Archibald, Esq., LL.D. F.R.S.E. F.G.S. Pres. Edin. Geol. Soc. Professor of Geology and Mineralogy in the University of Edinburgh, Director of the Geological Survey of Scotland. *Ramsay Lodge; and Geological Survey Office, Edinburgh.*
1860. June 7.	R. P.		Gilbert, Joseph Henry, Esq., Ph.D. V.P.C.S. *Harpenden, St. Albans.*
1853. June 2.	P.		Gladstone, John Hall, Esq., Ph.D. V.P.C.S. 17 *Pembridge-square.* W.
1849. June 7.	P.		Glaisher, James, Esq., F.R.A.S. 1 *Dartmouth-place, Blackheath.* S.E.
1839. Mar. 7.		†	Godwin, George, Esq., F.S.A. 6 *Cromwell-place, South Kensington.* S.W.
1849. June 7.		†	Godwin-Austen, Robert, Esq., V.P.G.S. *Chilworth Manor, Guildford.*
1830. Dec. 9.			Gordon, Sir Henry Percy, Bart., M.A. *Northcourt, Newport, Isle of Wight.*
1865. June 1.	P.		Gore, George, Esq. 50 *Islington-row, Edgbaston, Birmingham.*

Date of Election.		
1872. Jan. 18.		Goschen, Right Hon. George Joachim, First Lord of the Admiralty. 66 *Mount-street*, W.; *and Admiralty*, S.W.
1856. June 5.	P.	† Gosse, Philip Henry, Esq. *Sandhurst-villa, Marychurch, Torquay.*
1843. Jan. 19.		Gould, John, Esq., F.L.S. V.P.Z.S. 26 *Charlotte-street, Bedford-square.* W.C.
1865. June 1.		Grant, Robert, Esq., M.A. LL.D. (Aberd.) F.R.A.S. Regius Professor of Astronomy in the University of Glasgow. *Observatory, Glasgow.*
1873. June 12.		Grant, James Augustus, Lieut.-Colonel, C.B., C.S.I. 7 *Park-square West*, N.W.
1836. Feb. 4.		Grant, Robert Edmond, M.D. F.R.S.E. F.L.S. F.G.S. Professor of Comparative Anatomy and Zoology in University College. 2 *Euston-grove, Euston-square.* N.W.
1853. Jan. 13.		† Granville, George Leveson Gower, Earl, K.G. Chancellor of the University of London, Trust. Brit. Mus. *Carlton-house-terrace*, S.W.; *and Stone-park, Staffordshire.*
1832. Feb. 2.	P.	Gray, John Edward, Esq., Ph.D. V.P.Z.S. F.R.G.S. Soc. Imp. Hist. Nat. Mosq. Acadd. Lync. Romæ, Sc. Nat. Philad. et Hist. Nat. Boston. Socius, Keeper of the Zoological Collections of the British Museum. *British Museum.* W.C.
1870. June 2.		† Greenhow, Edward Headlam, M.D. Coll. Reg. Med. Soc. Physician to Middlesex Hospital. 14 A *Manchester-square.* W.
1830. June 10.		Greswell, Rev. Richard, M.A. 39 *St. Giles's-street, Oxford.*
1868. June 4.	P.	Griess, John Peter, Esq., F.C.S. *Burton-on-Trent.*
1840. Nov. 26.	R. P.	Grove, The Hon. Sir William Robert, Knt. M.A. Ph.D. Acadd. Reg. Sci. Taurin., Lync. Romæ, Soc. Phil. Basil. et Soc. Imp. Carob. Corresp. 115 *Harley-street.* W.
1864. June 2.		† Grubb, Thomas, Esq., M.R.I.A. 141 *Leinster-road, Dublin.*
1839. June 20.		Guest, Edwin, Esq., LL.D. Master of Caius College, Cambridge. *Caius Lodge, Cambridge; and Sandford-park, Oxfordshire.*
1869. June 3.		Gull, Sir William Withey, Bart., M.D. Coll. Reg. Med. Soc. Physician Extraordinary to the Queen. 74 *Brook-street.* W.
1839. Mar. 7.		Gulliver, George, Esq., F.R.C.S. 3 *Clovis-terrace, Canterbury.*
1854. June 1.		Gunn, Ronald Campbell, Esq., F.L.S. *Penquite, Launceston, Van Diemen's Land.*
1867. June 6.	P.	Günther, Albert C. L. G., M.A. M.D. Ph.D. Assistant-Keeper of the Zoological Collections in the British Museum. *British Museum.* W.C.
1871. June 8.	P.	Guthrie, Frederick, Esq., B.A. F.R.S.E. F.C.S. Professor of Physics in the Royal School of Mines. 24 *Stanley-crescent, Notting-hill*, W.; *and Royal School of Mines.* S.W.
1866. June 7.		† Guy, William Augustus, M.B. Physician to King's College Hospital, Coll. Reg. Med. Socius. 26 *Gordon-street, Gordon-square.* W.C.
1867. June 6.		† Haast, John Francis Julius, Esq., Ph.D. F.L.S. & G.S. Ord. Fr. Jos. Aust. Eq. Director of the Canterbury (N.Z.) Museum. Soc. Reg. Vict. Soc. pro. Phys. indag. Berol. et Soc. Hortic. Mogunt. Soc. Honor. Acad. Caes. Nat. Cur. Dresd. Soc. Germ. Geol. Berol. Soc. Imp. Zool. et Bot. Vindob. Socius. Soc. Geogr. Par. Imp. Geog. et Inst. Imp. Geol. Vindob. Acad. Reg. Sci. Bav. Monac. Soc. Reg. Bot. Ratisb. Soc. Senck. Nat. Soc. Geol. Edin. et Soc. Reg. Dubl. Corresp. *Glückauf, Christchurch, New Zealand.*
1847. Apr. 22.		† Hall, Sir William Hutcheson, Rear-Admiral, K.C.B. 48 *Phillimore-gardens, Kensington.* W.

Date of Election.			
1828. Jan. 17.			Hamilton, The Very Rev. H. Parr, Dean of Salisbury, M.A. F.G.S. F.R.A.S. *Salisbury.*
1833. Apr. 18.			Hamilton, The Right Hon. Robert C. Nisbet. 33 *Chesham-place.* S.W.
1867. June 6.			Hanbury, Daniel, Esq., Treas. L.S. *Clapham-common.* S.W.
1868. June 4.	P.		Harcourt, Augustus George Vernon, Esq., Lee's Reader in Chemistry, Sec. C.S. *Christ Church, Oxford.*
1838. April 5.		†	Hardwick, John, Esq., D.C.L.
1856. June 5.		†	Harkness, Robert, Esq., F.G.S. Professor of Geology, Queen's College, Cork. *Cork.*
1865. June 1.	P.		Harley, George, M.D. F.C.S. Acad. Sci. Monach. et Soc. Phys. Med. Herbip. Corr. Mem. 25 *Harley-street.* W.
1863. June 4.	P.		Harley, Rev. Robert, F.R.A.S. Lit. et Phil. Soc. Manc. Corr. Mem. *Mill Hill School, Middlesex,* N.W.; *and The Hawthornes, Church End, Finchley.* N.
1853. Nov. 24.		†	Harrowby, Dudley Ryder, Earl of, K.G. D.C.L. 39 *Grosvenor-square,* W.; *and Sandon-hall, Lichfield.*
1836. Dec. 22.		†	Hatherley, William Page Wood, Lord, D.C.L. (Oxon.) LL.D. (Cantab.). 31 *Great George-street.* S.W.
1858. June 3.	P.		Haughton, Rev. Samuel, M.D. M.A. M.R.I.A. F.G.S. Professor of Geology in the University of Dublin, Pres. Geol. Soc. Dublin. *Trinity College, Dublin.*
1834. Dec. 18.			Hawkins, Bissett, M.D. Coll. Reg. Med. Socius. 146 *Harley-street.* W.
1856. June 5.		†	Hawkins, Cæsar Henry, Esq., F.R.C.S. Serjeant-Surgeon to the Queen, Consulting Surgeon to St. George's Hospital. 26 *Grosvenor-street.* W.
1830. June 10.			Hawkins, John Heywood, Esq., M.A. F.G.S. *Reform Club,* S.W.; *and Bignor-park, Petworth, Sussex.*
1835. Nov. 19.		†	Hawkins, Rev. William Bentinck L., M.A. 33 *Bryanston-square.* W.
1855. June 7.			Hawkshaw, Sir John, Knt., M.I.C.E. F.G.S. 33 *Great George-street.* S.W.
1864. June 2.			Hay, Sir John Charles Dalrymple, Bart., Rear-Admiral, D.C.L. (Oxon.). 108 *St. George's-square,* S.W.; *and Dunragit, Wigtownshire, Scotland.*
1843. Feb. 2.		†	Heath, John Benjamin, Baron, F.S.A. 66 *Russell-square.* W.C.
1866. June 7.		†	Hector, James, M.D. Director of the Geological Survey, New Zealand, F.G.S. *Wellington, New Zealand.*
1858. June 3.	P.		Hennessy, Henry G., Esq., V.P.R.I.A. 86 *Stephen's-green, Dublin.*
1834. Apr. 10.			Henry, William Charles, M.D. F.C.S. *Haffield, near Ledbury, Herefordshire.*
1840. Feb. 27.		†	Henwood, William Jory, Esq., F.G.S. Soc. Phil. Ebor. Soc. Honor. Soc. Imp. Artib. Ut. Lugd. Gall. et Lyc. Nat. Hist. Nov. Ebor. Corr. Mem. 3 *Clarence-place, Penzance.*
1871. June 8.		†	Herschel, John, Capt. R.E. *Collingwood, Hawkhurst, Kent ; and East India Club.* S.W.
1839. Feb. 7.			Heywood, James, Esq., F.G.S. F.S.A. 26 *Kensington Palace-gardens,* W.; *and Athenæum Club.* S.W.
1862. June 5.		†	Hicks, John Braxton, M.D. F.L.S. Coll. Reg. Med. Soc. 24 *George-street, Hanover-square.* W.
1852. June 3.	P.	†	Higginbottom, John, Esq., F.R.C.S. *Gill-street, Nottingham.*
1857. June 11.		†	Hill, Sir Rowland, K.C.B. D.C.L. F.R.A.S. *Hampstead.* N.W.
1839. Jan. 10.		†	Hilton, John, Esq., F.R.C.S. Surgeon Extraordinary to the Queen, Surgeon to Guy's Hospital 10 *New Broad-street.* E.C.

Date of Election.			
1872. June 6.		†	Hincks, Rev. Thomas, B.A. (Lond.). *Charlemont, Taunton.*
1863. June 4.	R.	†	Hind, John Russell, Esq., F.R.A.S. Inst. Fr. (Acad. Sci.) Par. Corr., Superintendent of the Nautical Almanac. *Mr. Bishop's Observatory, Twickenham.* S.W.
1855. June 7.		†	Hippisley, John, Esq., F.R.A.S. *Athenæum,* S.W.; *and Ston Easton, Bath.*
1861. June 6.	P.		Hirst, Thomas Archer, Esq., Ph.D. (Marp.) F.R.A.S. Director of Studies, Royal Naval College, Greenwich. President of the London Mathematical Society, Soc. Nat. Hist. stud. Marp. Soc. extr. Soc. Nat. Scrutat. Halae. Socius, et Soc. Philom. Par. Corresp. *Royal Naval College, Greenwich,* S.E.; *and Athenæum Club.* S.W.
1851. June 5.	R. P.		Hofmann, A. W., LL.D. Ph.D. V.P.C.S. Ord. Leg. Hon. S.S^{rum} Lazar. et Maurit. Ital. Eq., Inst. Fr. (Acad. Sci.) Par., Acad. Imp. Sci. Petrop., Imp. Reg. Vindob., Acad. Reg. Sci. Amstelod. Berol., Monac., Taur., Societ. Philomat. Paris., Phil. Amer. Philad., Phys. Francof., Bat. Roterod., Nat. Neo-Granad., Nat. Halae. Univ. Cas., Phys. Med. Erlang. Indust. Mulh. Corresp. 10 *Dorotheen Strasse, Berlin.*
1837. Jan. 19.			Holland, Charles, M.D. *St. Chad's, Lichfield.*
1843. Dec. 7.			Hood, Charles, Esq., F.R.A.S. *Earl-street, Blackfriars,* E.C.; *and Gremgewood, Upper Norwood.* S.E.
1862. June 5.		†	Hook, The Very Rev. Walter Farquhar, D.D. Dean of Chichester. *The Deanery, Chichester.*
1847. Apr. 22.	R.P.		Hooker, Joseph Dalton, C.B. M.D. D.C.L. LL.D. V.P.L.S. F.G.S. Director of the Royal Gardens, Kew.—PRESIDENT.—Inst. Fr. (Acad. Sci.) Par. Corresp. *Kew.* W.
1841. May 20.			Hoppus, Rev. John, LL.D. Ph.D. Emeritus Professor of Philosophy and Logic, University College, London. 26 *Camden-street, Camden-town.* N.W.
1843. May 25.	P.		Hoskins, Samuel Elliott, M.D. Coll. Reg. Med. Soc. late Inspector-General Guernsey Royal Militia. *Guernsey.*
1868. Dec. 10.		†	Houghton, Richard Monckton Milnes, Lord, M.A. D.C.L. (Oxon.). *Travellers' Club, Pall Mall,* S.W.; *and Frystone Hall, Bawtry, Yorkshire.*
1834. Apr. 10.			Hudson, Robert, Esq., F.G.S. F.L.S. *Clapham-common.* S.W.
1865. June 1.	R.P.		Huggins, William, Esq., D.C.L. (Oxon.) LL.D. (Cantab. et Edin.) For. Sec. R.A.S. Soc. Reg. Sci. Hafn. Physiogr. Lund. Reg. Dubl. et Soc. Lit. Phil. Manc. Soc. Honor. Acad. Lync. Romae. Mem. Corr. *Upper Tulse-hill.* S.W.
1867. June 6.	P.		Hulke, John Whitaker, Esq., F.R.C.S. Surgeon to the Royal London Ophthalmic Hospital and the Middlesex Hospital. 10 *Old Burlington-street.* W.
1867. June 6.		†	Hull, Edward, Esq., M.A. F.G.S. Director of the Geological Survey of Ireland and Professor of Geology in the Royal College of Science. 14 *Hume-street, Dublin.*
1859. June 9.		†	Humphry, George Murray, M.D. Professor of Anatomy in the University of Cambridge. *The Leys, Cambridge.*
1854. June 1.	P.	†	Hunt, Robert, Esq., Keeper of Mining Records. *Museum of Practical Geology, Jermyn-street; and* 26 *St. Leonard's-terrace, Chelsea.* S.W.
1859. June 5.		†	Hunt, Thomas Sterry, Esq., M.A. (Harvard) Sc.D. LL.D. Soc. Phil. Amer. Philad., Acad. Amer. Bost., Soc. Hist. Nat. Bost., Soc. Amer. Geogr. et Stat. Nov. Ebor., Imp. Leop. Car. Acad. Nat. Cur. Dresd., Soc. Geol. Dublin, Soc. Geol. Fr., Inst. Imp. Geol. Vindob. Socius, Leg. Hon. Off. *Institute of Technology, Boston, U. S.*

Date of Election.			
1851. June 5.	R.P.		Huxley, Thomas Henry, Esq., LL.D. (Edin.) Ph.D. (Breslau).—SECRETARY.—Professor of Natural History in the Royal School of Mines, South-Kensington Museum, F.G.S. V.P.Z.S. F.L.S. Acadd. Imp. Sci. Petrop. Reg. Sci. Berol. Reg. Sci. Monach. Cæs. Nat. Cur. Dresd. Nat. Sci. Philad. Soc. Reg. Sci. Gött. et Soc. Anthrop. Par. Corresp. Inst. Egypt. Soc. Honor. *School of Mines, South-Kensington Museum ; and* 4 *Marlborough-place, Abbey-road.* N.W.
1844. Feb. 29.		†	Hyett, William Henry, Esq. *Painswick, Gloucestershire.*
1838. May 31.			Hymers, Rev. John, D.D. *Brandsburton Rectory, near Beverley.*
1853. June 2.			Inglefield, Edward Augustus, Rear-Admiral, F.R.G.S. *United Service Club.* S.W.
1870. June 2.		†	Jago, James, M.D. (Oxon.) A.B. (Cantab.). *Lemon House, Truro.*
1848. June 9.	P.	†	James, Sir Henry, Major-General R.E. M.R.I.A. F.G.SS.L. & D. *Topographical Depôt,* 4 *New-street,* S.W. ; *and Ordnance Survey Office, Southampton.*
1860. June 7.		†	Jardine, Sir William, Bart., F.R.S.E. F.L.S. *Jardine-hall, Lockerbie, Dumfriesshire.*
1840. April 2.		†	Jeffreys, John Gwyn, Esq., Treas. G.S. Soc. Imp. Reg. Zool.-Bot. Vindob. Acadd. Nat. Scrutat. Berol. Reg. Pelor. Mess. Hist. Nat. Stud. Megalop. et Sci. Nat. Philad. Corresp. 33 *Grosvenor-street,* W. ; *and Ware Priory, Ware, Herts.*
1841. Jan. 7.		†	Jeffreys, Julius, Esq. 3 *Broomfield, Bromley, Kent.*
1865. June 1.	P.		Jenkin, Henry Charles Fleeming, Esq., M.I.C.E. Professor of Civil Engineering in the University of Edinburgh. 5 *Fettes-row, Edinburgh ; and Claygate, near Esher, Surrey.*
1864. June 2.			Jenner, Sir William, Bart., K.C.B. M.D. D.C.L. (Oxon.) Physician in Ordinary to the Queen, Professor of Clinical Medicine in University College, London. 63 *Brook-street.* W.
1872. June 6.	P.		Jevons, William Stanley, Esq., M.A. (Lond.) Professor of Logic and Political Economy in Owens College, Manchester. *Parsonage-road, Withington, Manchester.*
1842. Mar. 10.		†	Johnson, Cuthbert William, Esq. *Waldronhyrst, Croydon.*
1872. June 6.		†	Johnson, George, M.D. Coll. Reg. Med. Soc. Professor of Medicine in King's College, London. 11 *Savile-row.* W.
1838. Jan. 18.			Johnson, The Very Rev. George Henry Sacheverell, M.A. Dean of Wells. *Wells.*
1845. June 5.			Johnston, Alexander Robert, Esq. *Heatherley, near Wokingham.*
1850. June 6.	P.		Jones, Charles Handfield, M.B. Coll. Reg. Med. Socius, Physician to St. Mary's Hospital. 49 *Green-street, Park-lane.* W.
1872. June 6.	P.		Jones, Thomas Rupert, F G.S. Professor of Geology at the Royal Military and Staff Colleges, Sandhurst, K.K. Geol. Reichsanst. Vindob. et Acad. Sci. Nat. Philad. Corresp. 5 *College-terrace, York-town, Surrey.*
1844. Mar. 21.		†	Jones, Thomas Rymer, Esq., Professor of Comparative Anatomy, King's College. 52 *Cornwall-road, Westbourne-park.* W.
1840. Apr. 30.	P.	†	Jones, Thomas Wharton, Esq., F.R.C.S. Professor of Ophthalmic Medicine and Surgery, University College, and Ophthalmic Surgeon to the Hospital, Soc. de Biologie Par. Mem. Corr. 35 *George-street, Hanover-square.* W.
1850. June 6.	C. R. P.		Joule, James Prescott, Esq., LL.D. F.C.S. Cam. Phil. Soc., Inst. Engineers Scotland, Phil. Soc. Glasgow, Phil. Inst. Birkenhead, Inst. Fr. (Acad. Sci.) Par. Soc. Phil. Nat. Basil. Hon. Mem. Acad. Reg. Sci. Taurin. Corresp. *Cliff Point, Higher Broughton, Manchester.*

Date of Election.			
1849. June 7.	R. P.		Kane, Sir Robert, M.D. LL.D. M.R.I.A. F.C.S. Principal of the Royal College of Cork. 51 *Stephen's-green, Dublin.*
1846. Feb. 26.			Kay, Joseph Henry, Captain R.N. *Melbourne, Victoria.*
1866. June 7.		†	Kaye, Sir John William, K.C.S.I. *India Office, Westminster,* S.W.; *and Rose-hill, Forest-hill.* S.E.
1838. Dec. 6.		†	Kelland, Rev. Philip, M.A. V.P.R.S.E. M.C.P.S. Professor of Mathematics in the University of Edinburgh. 20 *Clarendon-crescent, Edinburgh.*
1868. June 4.		†	Key, Sir Astley Cooper, Vice-Admiral, K.C.B. F.R.G.S. President of the Royal Naval College. *Greenwich.* S.E.
1860. June 7.		†	Key, Thomas Hewitt, Esq., M.A. F.C.P.S. Professor of Comparative Grammar, University College, London. 21 *Westbourne-square.* W.
1834. Dec. 18.	C. P.		Kiernan, Francis, Esq., F.R.C.S. 30 *Manchester-street.* W.
1857. June 11.	P.		Kirkman, Rev. Thomas Penyngton, M.A. Soc. Lit. & Phil. Manc. et Eleutherop. Hon. Mem. et Soc. Batav. Sci. Harl. Soc. Extr. *Croft Rectory, near Warrington.*
1830. Mar. 4.			Knowles, Sir Francis Charles, Bart., M.A. *Mayfield, Ryde.*
1845. Dec. 19.		†	Lankester, Edwin, M.D. Coroner for Central Middlesex. 68 *Belsize-park.* N.W.
1844. May 16.			Larcom, Sir Thomas Aiskew, Bart., Major-General, K.C.B. R.E. M.R.I.A. *Heathfield, Fareham, Hants.*
1849. June 7.	R.	†	Lassell, William, Esq., V.P.R.A.S. R.S.Edin. et Soc. Lit. Phil. Manc. Soc. Honor. Soc. Reg. Sci. Upsal et Soc. Philom. Par. Mem. Corr. *Ray Lodge, Maidenhead; and Athenæum Club.* S.W.
1854. June 1.	R. P.		Lawes, John Bennet, Esq., F.C.S. *Rothamsted, St. Albans.*
1843. May 11.		†	Le Couteur, Sir John, Colonel. *Belle Vue, Jersey.*
1830. Mar. 25.	P.		Lee, Robert, M.D. Coll. Reg. Med. Socius. 4 *Savile-row.* W.
1820. Nov. 16.			Lefevre, Sir John George Shaw, K.C.B. M.A. D.C.L. 18 *Spring-gardens.* S.W.
1848. June 9.		†	Lefroy, John Henry, Major-General, R.A., C.B., Governor of Bermuda, F.R.G.S. Arch. Inst. Soc. Nat. Hist. Montr. et Inst. Can. Socius. *Bermuda.*
1860. June 7.	P.		Lister, Joseph, Esq., F.R.C.S. Professor of Clinical Surgery in the University of Edinburgh, Surgeon in Ordinary to the Queen. *Edinburgh.*
1858. June 3.		†	Livingstone, David, LL.D. D.C.L. H.B.M. Consul to the Interior Tribes of Africa, Inst. Fr. (Acad. Sci.) Par. Corresp.
1836. Feb. 4.			Llewelyn, John Dillwyn, Esq., F.L.S. 39 *Cornwall-gardens,* W.; *and Pennllegare, Glamorgan.*
1836. Jan. 21.			Lloyd, Rev. Humphrey, D.D. M.R.I.A. Provost of Trinity College, Dublin, Soc. Reg. Sci. Gott. Corresp. *Trinity College, Dublin.*
1869. June 3.	P.	†	Lockyer, Joseph Norman, Esq., F.R.A.S. 5 *Alexandra-road, Finchley-road.* N.W.
1864. June 2.		†	Locock, Sir Charles, Bart., M.D. Physician to the Queen. 26 *Hertford-street.* W.
1851. June 5.	R.	†	Logan, Sir William Edmond, LL.D. F.G.S. V.P. Nat. Hist. Soc. Montreal. *Rockfield, Montreal.*
1841. Nov. 25.		†	Lovelace, William King, Earl of. *East Horseley-park, Ripley, Surrey; and Ashley-combe, Porlock, Somerset.*
1867. June 6.		†	Lowe, Edward Joseph, Esq., F.R.A.S. L.S. G.S. Z.S. M.S. Soc. Lit. et Phil. Manc. et Lyc. Hist. Nat. Nov. Ebor. Mem. Corr. *Highfield House, near Nottingham.*

Date of Election.		
1871. May 25.		† Lowe, Right Hon. Robert, Secretary of State, Home Department, LL.D. (Edin.). 34 *Lowndes-square*, S.W.; *and Caterham, Redhill, Surrey.*
1858. June 3.	P.	Lubbock, Sir John, Bart. V.P.L.S. F.G.S. & E.S. *High Elms, Bromley, Kent.*
1855. June 7.		† Luke, James, Esq., F.R.C.S. Consulting Surgeon to the London Hospital. *Woolley-lodge, Maidenhead Thicket, Berks.*
1826. Feb. 2.	C. R.P.	Lyell, Sir Charles, Bart. LL.D. D.C.L. Hon. M.R.S.Ed. F.L.S. V.P.G.S. Ord. Boruss. "*Pour le Mérite*" Eq., Inst. Fr. (Acad. Sci.) Par. Acad. Reg. Berol. Monach. Reg. Sc. Hafn. Sc. Sci. Phys. Bonn. Acad. Nat. Sci. et Am. Phil. Soc. Philad. Am. Acad. Art. et Sci. et Soc. Nat. Hist. Bost. Corr. Mem. 73 *Harley-street.* W.
1840. Apr. 30.		† Lyttelton, George William, Lord, D.C.L. (Oxon.). 42 *Portland-place*, W.; *and Hagley-park, near Stourbridge, Worcestershire.*
1865. June 1.		McClintock, Sir Francis Leopold, Rear-Admiral. *H. M. Dockyard, Portsmouth.*
1859. June 9.	P.	† Macdonald, John Denis, Esq., M.D. Staff-Surgeon R.N. Assistant Professor of Naval Hygiene in the Netley Medical School. *Royal Victoria Hospital, Netley, Southampton.*
1865. June 1.		McDonnell, Robert, M.D. M.R.I.A. Examiner in Surgery in the Queen's University, Ireland. 14 *Lower Pembroke-street, Dublin.*
1831. Dec. 8.	R.P.	Maclear, Sir Thomas, F.R.A.S. Inst. Fr. (Acad. Sci.) Par. Corr. *Capetown, South Africa.*
1838. April 5.		† Macneill, Sir John, LL.D. F.R.A.S. M.R.I.A. 17 *The Grove, South Kensington.* S.W.
1860. June 7.		† Main, Rev. Robert, M.A. V.P.R.A.S. Director of the Radcliffe Observatory, Oxford. *Oxford.*
1854. June 1.	P.	Mallet, Robert, Esq., C.E. M.R.I.A. 7 *Westminster-chambers, Victoria-street*, S.W.; *and Enmore, The Grove, Clapham-road.* S.W.
1853. June 2.		† Manby, Charles, Esq., F.G.S. 60 *Westbourne-terrace, Hyde-park.* W.
1836. Jan. 28.		Marcet, Francis, Esq. 14 *Stratton-street.* W.
1857. June 11.	P.	Marcet, William, M.D. F.C.S. *Athenæum Club*, S.W.; *and* 12 *Quai Masséna, Nice.*
1873. June 12.		† Markham, Clements Robert, Esq., C.B. Sec. R.G.S. F.L.S. F.S.A. Acad. Caes. Nat. Cur. Socius Soc. Geog. Par. Berol. Vindob. Hist. Philad. et Univ. Chil. Soc. Honor. *Athenæum Club; and* 21 *Eccleston-square.* S.W.
1857. June 11.	P.	Marshall, John, Esq., F.R.C.S. Surgeon to University College Hospital, Professor of Anatomy to the Royal Academy of Arts. 10 *Savile-row.* W.
1845. Feb. 13.		Martin, Sir James Ranald, C.B. F.R.C.S. M.R.A.S. 37 *Upper Brook-street.* W.
1823. Nov. 27.		Maskelyne, Anthony Mervin Story, Esq., M.A. *Bassett Down-house, Swindon.*
1870. June 2.	P.	Maskelyne, Nevil Story, Esq., M.A. F.G.S. Keeper of the Mineral Department, British Museum. Soc. Imp. Min. Petrop. et Soc. Hist. Nat. Bost. Soc. 112 *Gloucester-terrace, Hyde-park-gardens.* W.
1870. June 2.		† Masters, Maxwell Tylden, M.D. M.R.C.S. F.L.S. *Mount Avenue, Ealing.* W.
1846. Feb. 19.		† Matheson, Sir James, Bart. 13 *Cleveland-row.* S.W.
1861. June 6.	Rm. P.	Maxwell, James Clerk, Esq., M.A. Professor of Experimental Physics in the University of Cambridge. 11 *Scroope-terrace, Cambridge; and Glenlair, Dalbeattie, Scotland.*

Date of Election.		
1863. June 4.	P.	† Merrifield, Charles Watkins, Esq., Hon. Sec. I.N.A. 20 *Pembroke-gardens, Kensington.* W.
1843. Mar. 9.		† Miers, John, Esq., F.L.S. Dign. et Commendador Ord. Bras. Rosac. Acad. Cæs. Nat. Cur. et Reg. Bot. Ratisb. Soc. 84 *Addison-road, Kensington.* W.
1838. Feb. 8.	R.P.	Miller, William Hallowes, Esq., M.A. LL.D. (Dubl.) Professor of Mineralogy in the University of Cambridge, F.G.S. F.C.S. Ord. SS$^{\text{rum}}$ Maur. et Lazar. Ital. Eq. Inst. Fr. (Acad. Sci.) Par. Acad. Reg. d. Imp. Sci. Petrop. Reg. Sci. Berol. Taurin. et Monach. Corr. Mem. Soc. Reg. Sci. Gött. et Min. Petrop. Soc. Extr. 7 *Scroope-terrace, Cambridge.*
1869. June 3.	P.	Mivart, St. George, Esq., F.L.S. F.Z.S. Lecturer on Comparative Anatomy, St. Mary's Hospital. 10 *George-street, Hanover-square* W.
1871. June 8.		Moncrieff, Alexander, Major Militia Artil., Ordnance Engineer. *Athenæum Club.* S.W.
1836. June 16.		Montefiore, Sir Moses, Bart. 7 *Grosvenor-gate,* W.; *and East-Cliff Lodge, Ramsgate.*
1872. June 6.		† Montgomerie, Thomas George, Major R.E. Deputy Superintendent of the Great Trigonometrical Survey of India. *Mussoorie, North-west Provinces, India.*
1856. June 5.		† Moore, John Carrick, Esq., M.A. F.G.S. 113 *Eaton-square,* S.W.; *and Corswall, Stranraer, Wigtonshire.*
1832. Feb. 2.		† Morgan, Octavius S., Esq., M.A. F.S.A. 10 *Charles-street, St. James's-square,* S.W.; *and Tredegar-park, Monmouthshire.*
1861. June 6.		Mueller, Baron Ferdinand von, M.D. Comp. Ord. St. Michael & St. George, F.L.S. Government Botanist, and Director of the Melbourne Botanic Garden. *Melbourne, Victoria.*
1866. June 7.	P.	Müller, Hugo, Esq., Ph.D. For. Sec. C.S. *Woburn Lodge, Upper Woburn-place,* W.C.; *and* 110 *Bunhill-row.* E.C.
1866. June 7.		Murchison, Charles, M.D. LL.D. (Edin.) Physician to Middlesex Hospital, Coll. Reg. Med. Socius. 79 *Wimpole-street.* W.
1860. June 7.		† Mylne, Robert William, Esq., F.G.S. F.S.A. 21 *Whitehall-place.* S.W.
1867. June 6.		Napier, James Robert, Esq., M.I.N.A. 22 *Blythswood-square, Glasgow.*
1869. Dec. 16.		† Napier of Magdala, Robert Lord, G.C.B. G.C.S.I. *India; and Bryngwyn, Oswestry.*
1861. June 6.		Newmarch, William, Esq. *Beech Holme, Clapham Common.* S.W.
1870. June 2.	P.	Newton, Alfred, Esq., M.A. V.P.Z.S. M.C.P.S. F.L.S. Professor of Zoology and Comparative Anatomy in the University of Cambridge. *Magdalene College, Cambridge.*
1856. June 5.	P.	† Noad, Henry Minchin, Esq., Ph.D. V.P.C.S. *St. George's Hospital.* S.W.
1870. June 2.		Noble, Andrew, Capt. F.R.A.S. F.C.S. *Jesmond Dene, Newcastle-upon-Tyne.*
1859. June 9.		† Odling, William, M.B. Coll. Reg. Med. Socius. P.C.S. Waynflete Professor of Chemistry in the University of Oxford. *Museum, Oxford.*
1848. June 9.		† Oldham, Thomas, Esq., LL.D. M.A. F.G.S. M.R.I.A. Superintendent of the Geological Survey of India. *Calcutta.*
1863. June 4.		Oliver, Daniel, Esq., F.L.S. Professor of Botany, University College, London. *Royal Gardens, Kew.* W.
1868. June 4.		Ommanney, Erasmus, Vice-Admiral, C.B. F.R.A.S. & G.S. 6 *Talbot-square, Hyde-park,* W.; *and United Service Club.* S.W.

Date of Election.		
1870. June 2.		† Osborn, Sherard, Rear-Admiral, C.B. F.R.G.S. F.L.S. Leg. Imp. Honor. et Medjidee Com. 6 *Gloucester-terrace, Hyde-park.* W.
1855. June 7.		† Osler, Abraham Follett, Esq. *South Bank, Edgbaston, Birmingham.*
1834. Dec. 18.	C.R. P.	Owen, Richard, Esq., C.B. M.D. D.C.L. LL.D. F.L.S. F.G.S. V.P.Z.S. Director of the Natural-History Department, British Museum, Coll. Reg. Chir. Hib. et Soc. Reg. Edin. Soc. Honor., Ord. Boruss. "*Pour le Mérite*" Eq., Inst. Fr. (Acad. Sci.) Par., Acadd. Imp. Sci. Vindob., Petrop., et Soc. Imp. Sc. Nat. Hist. Mosq., Acadd. Reg. Sci. Berol., Taurin., Madrit., Holm., Monach., Neapol., Bruxell., Bonon., Instit. Reg. Sc. Amstelod., Socc. Reg. Sc. Hafn., Upsal., Acad. Amer. Sc. Bost. Socius, Soc. Philomath. Paris. Corresp., Imp. Geor. Florent., Socc. Sc. Harlem., Trajectin., Phys. et Hist. Nat. Genev., Acadd. Lync. Romæ, Patav., Panorm., Gioen. Nat. Scrutat. Berolin., Instit. Wetter., Philad., Nov.-Ebor., Bost., Acad. Reg. Med. Paris. Soc. Imp. et Reg. Med. Vindob. Adsocius Extraneus. *British Museum,* W.C.; *and Sheen Lodge, Mortlake.* S.W.
1873. June 12.		† Paget, George Edward, M.D. (Cantab. et Dubl.) D.C.L. (Oxon. et Dunelm) LL.D. (Edin.) Regius Professor of Physic in the University of Cambridge. *Cambridge.*
1851. June 5.	P.	† Paget, Sir James, Bart., D.C.L. (Oxon.) Serjeant-Surgeon Extraordinary to the Queen, Surgeon in Ordinary to H.R.H. The Prince of Wales, F.R.C.S. 1 *Harewood-place, Hanover-square.* W.
1858. June 17.		† Pakington, Right Hon. Sir John, Bart., G.C.B. 9 *Eaton-square,* S.W.; *and Westwood-park, Droitwich.*
1824. Mar. 4.	P.	Parish, Sir Woodbine, K.C.H. F.G.S. *St. Leonard's.*
1865. June 1.	R.P.	Parker, William Kitchen, Esq., F.Z.S. Acad. Sci. Nat. Philad. Soc. Corr. 36 *Claverton-street.* S.W.
1861. June 6.		† Parkes, Edmund Alexander, M.D. Professor of Hygiene, Army Medical School. *Sydney Cottage, Bitterne, Southampton.*
1870. June 2.		Parkinson, Rev. Stephen, D.D. President and Tutor of St. John's College. *St. John's College, Cambridge.*
1870. June 2.		† Parsons, R. Mann, Lieut.-Col. R.E. F.R.A.S. *Ordnance Survey Office, Southampton.*
1863. June 4.	P.	† Pavy, Frederick William, M.D. Coll. Reg. Med. Socius, Lecturer on Physiology and Comparative Anatomy and Zoology at Guy's Hospital. 35 *Grosvenor-street.* W.
1833. Dec. 5.		Pearson, Sir Edwin, Knt. M.A. *Wimbledon.* S.W.
1863. June 4.	P.	Pengelly, William, Esq., F.G.S. *Lamorna, Torquay.*
1859. June 9.		Penn, John, Esq. *The Cedars, Lee, Kent.* S.E.
1847. Apr. 22.		† Percy, John, M.D. F.G.S. Professor of Metallurgy in the Royal School of Mines. *Museum of Economic Geology, Jermyn-street,* S.W.; *and* 1 *Gloucester-crescent, Hyde-park.* W.
1866. June 7.		Perkin, William Henry, Esq., Sec.C.S. *Seymour-villa, Sudbury.* N.W.
1868. June 4.	P.	Pettigrew, James Bell, M.D. (Edin.), Pathologist to the Royal Infirmary, and Curator of the Royal College of Surgeons of Edinburgh. *Royal College of Surgeons, Edinburgh.*
1839. May 30.		Phillipps, James Orchard, Esq., Hon. M.R.I.A. & R.S.L. F.S.A.L. & E. 11 *Tregunter-road, South Kensington.* S.W.

Date of Election.		
1834. Apr. 10.		† Phillips, John, Esq., M.A. LL.D. F.G.S. Acad. Imp. Mosq. et Acad. Sci. Philad. Soc. Honor., Reader in Geology in the University of Oxford. *Museum-house, Oxford.*
1848. June 9.	P.	† Playfair, Lyon, Right Hon., C.B. LL.D. Ph.D. V.P.C.S. & R.S.E. Leg. Honor. Off. Stell. Bor. Succ. Eq. 4 *Queensberry-place, S. Kensington.* S.W.
1847. Apr. 15.		† Plowden, William Henry Chicheley, Esq. *Ewhurst-park, Basingstoke.*
1829. Apr. 9.		Pole, William, Esq., M.A. 13 *Devonshire-place, Portland-place.* W.
1861. June 6.	P.	Pole, William, Esq., Mus. Doc. Oxon. M.I.C.E. *Athenæum Club.* S.W.
1856. June 5.		† Potter, Edmund, Esq. *Camfield-place, Hatfield, Herts.*
1853. June 2.	R. P.	† Prestwich, Joseph, Esq., V.P.G.S. F.C.S. Assoc. I.C.E. Soc. Geol. Fr. Socius. Inst. Imp. Geol. Vindob. Soc. Reg. Geol. Cornub. Corr. Amer. Phil. Soc. Philad. Pont. Acad. Romæ. et Soc. Lit. Phil. Manc. Soc. Honor. *Darent-Hulme, Shoreham, Kent.*
1852. June 3.		Price, Rev. Bartholomew, M.A. F.R.A.S. Sedleian Professor of Natural Philosophy, Oxford. *Pembroke College; and* 11 *St. Giles's, Oxford.*
1840. Feb. 6.		† Pritchard, Rev. Charles, M.A. F.R.A.S. F.G.S. F.C.P.S. Savilian Professor of Astronomy, Oxford. 8 *Keble-terrace, Oxford.*
1844. Feb. 29.		† Quain, Richard, Esq., F.R.C.S. Surgeon Extraordinary to the Queen. 32 *Cavendish-square.* W.
1871. June 8.		Quain, Richard, M.D. Coll. Reg. Med. Soc. 67 *Harley-street.* W.
1849. June 7.		† Ramsay, Andrew Crombie, Esq.—VICE-PRESIDENT.—LL.D. V.P.G.S. Director-General of the Geological Survey of the United Kingdom, and of the Museum of Economic Geology, Professor of Geology in the Royal School of Mines, Ord. SS$^{\text{rum}}$ Maur. et Lazar. Eq., Acad. Sci. Brux. Assoc. Amer. Phil. Soc. Philad. Socius, et Nat. Sc. Soc. Ital. Corresp. *Geological Survey Office, Jermyn-street.* S.W.
1870. June 2.	P.	Ransom, William Henry, M.D. Coll. Reg. Med. Soc. Physician to the General Hospital, Nottingham. *The Pavement, Nottingham.*
1850. June 6.		† Rawlinson, Major-Gen. Sir Henry Creswicke, K.C.B. D.C.L. Pres. R.G.S. Ord. Boruss. "*Pour le Mérite*" Eq. Inst. Fr. (Acad. Inscrip.) Par. Corresp. *Athenæum Club*, S.W.; *and* 21 *Charles-street, Berkeley-square.* W.
1873. June 12.	P.	Rayleigh, John William Strutt, Baron, M.A. *Terling-place, Witham, Essex.*
1843. Feb. 2.	P.	Rees, George Owen, M.D. F.G.S. Coll. Reg. Med. Socius, Physician to Guy's Hospital. 26 *Albemarle-street.* W.
1834. Feb. 6.		Reeves, John Russell, Esq., F.L.S. *Woodhays, Wimbledon.* S.W.
1823. June 12.		Rennie, Sir John, Knt., F.G.S. 18 *Lowndes-street.* S.W.
1845. May 22.		Rennie, James, Esq. 9 *Motcombe-street, Belgrave-square.* S.W.
1869. June 3.		† Reynolds, John Russell, M.D. Professor of Medicine in University College, London, Acad. Caes. Leop. Socius. 38 *Grosvenor-street.* W.
1866. June 7.		† Richards, George Henry, Rear-Admiral, C.B. Hydrographer of the Admiralty, V.P.R.G.S. Inst. Fr. (Acad. Sci.) Par. Corresp. Soc. Geog. Berol. et Soc. Geog. Ital. Flor. Inst. Nov. Zel. Soc. Honor. *The Admiralty, Whitehall*, S.W.; *and* 12 *Westbourne-terrace-road.* W.
1867. June 6.		† Richardson, Benjamin Ward, M.D. M.A. Coll. Reg. Med. Soc. Honorary Physician to the Royal Literary Fund. Acad. Caes. Leop. Nat. Cur. Dresd. Amer. Phil. Soc. Philad., Acad Phys. Med. Stat. Mediol. et Phil. Soc. Andreap. Socius. 12 *Hinde-street*, W.; *and Boundary-house, St. John's Wood*, N.W.

Date of Election.			
1842. Jan. 13.			Riddell, Charles James Buchanan, Major-General R.A. C.B. *Oaklands, Chudleigh, Devonshire.*
1858. Dec. 16.		†	Ripon, Robert Bickersteth, Lord Bishop of. *Palace, Ripon; and* 11 *Onslow-crescent.* S.W.
1860. May 24.		†	Ripon, George Frederick Samuel Robinson, Marquis of, K.G. D.C.L. (Oxon.) F.L.S. F.R.G.S. 1 *Carlton-gardens*, S.W.; *and Studley Royal, Ripon, Yorkshire.*
1869. June 3.		†	Robinson, Sir Robert Spencer, Admiral, K.C.B. 61 *Eaton-place.* S.W.
1856. June 5.	R. P.	†	Robinson, Rev. Thomas Romney, D.D. Director of the Armagh Observatory, M.R.I.A. F.R.A.S. Ord. Boruss. "*Pour le Mérite*" Eq., Soc. Phil. Cantab., Inst. Civ. Eng., Soc. Reg. Dub., Acad. Pennsylv., Mem. Honor. et Acad. Panorm. Mem. Corr. *Armagh.*
1862. June 5.	P.	†	Rolleston, George, M.D. M.A. F.L.S. Coll. Reg. Med. Soc. Linacre Professor of Anatomy and Physiology in the University of Oxford. 15 *New Inn Hall-street, Oxford.*
1863. June 4.	R. P.		Roscoe, Henry Enfield, Esq., B.A. Ph.D. F.C.S. Professor of Chemistry in Owens College, Manchester. *Manchester.*
1834. June 5.			Rose, The Right Hon. Sir George, Knt. 4 *Hyde-park-gardens.* W.
1867. Dec. 19.	P.		Rosse, Laurence Parsons, Earl of, B.A. D.C.L. (Oxon.) F.R.A.S. *Birr Castle, Parsonstown, Ireland; and Heaton-hall, Bradford, Yorkshire.*
1872. June 6.			Routh, Edward John, Esq., M.A. F.R.A.S. F.G.S. *Newnham, Cambridge.*
1873. June 12.	P.		Royston-Pigott, George West, M.A. M.D. (Cantab.) Coll. Reg. Med. Soc. F.C.P.S. F.R.A.S. *Hartley Court, near Reading.*
1821. June 7.			Russell, Jesse Watts, Esq., D.C.L. F.S.A. F.L.S. F.G.S. *Ilam-hall, Ashbourn.*
1847. May 6.		†	Russell, John, Earl, K.G. K.G.C. Ord. St. Michael & St. George, Trust. Brit. Mus. 37 *Chesham-place, Belgrave-square.* S.W.
1849. June 7.		†	Russell, John Scott, Esq. 5 *Westminster Chambers, Victoria-street.* S.W.
1866. June 7.	P.		Russell, William Henry Leighton, Esq., A.B. *The Grove, Highgate.* N.
1872. June 6.		†	Russell, William James, Esq., Ph.D. V.P.C.S. Lecturer on Chemistry at the Medical School of St. Bartholomew's Hospital. 34 *Upper Hamilton-terrace.* N.W.
1860. Feb. 2.		†	Ryan, The Right Hon. Sir Edward, M.A. F.G.S. F.R.A.S. F.A.S. 5 *Addison-road.* W.
1818. Apr. 16.	C. R. P.		Sabine, General Sir Edward, R.A. K.C.B. D.C.L. (Oxon.) LL.D. (Cantab). Hon. F.R.S. Edin. F.R.A.S. F.L.S. Ord. Boruss. "*Pour le Mérite,*" Ord. SS^{rum} Maur. et Lazar. Ital. Eq. et Ord. Imp. Bras. Rosae. Dign. Soc. Phil. Cam. Nat. Hist. Montr. Acadd. Imp. Sci. Petrop., Reg. Sci. Berol., Brux., Norv., Soc. Geog., Vindob. Soc. Geog. Ital. Flor. Phil. et Œcon. Siles. Soc. Reg. Batav. Gotting., Hafn. et Inst. Conimb. Socius: Acadd. Reg. Sci. Taur. Acad. Nuov. Lync. Romæ, Vaud., Inst. Nat. Washington U.S. Soc. Phys. Med. Herbip. Soc. Geogr. Par. Berol. Petrop. et Acadd. Sci. Carob. Mem. Corr. Acad. Reg. Sci. Holm. Soc. Physiogr. Lund. Soc. Ital. Sci. Mod. Soc. Extr. Soc. Sci. Phys. et Nat. Carácas. et Soc. Teleg. Eng. Soc. Honor. 13 *Ashley-place, Westminster.* S.W.

Date of Election.		
1869. Jan. 28.		† Salisbury, Robert Arthur Talbot Gascoigne-Cecil, Marquis of, M.A. Chancellor of the University of Oxford. 20 *Arlington-street*, S.W.; *and Hatfield-house, Hatfield, Herts.*
1863. June 4.	R.P.	Salmon, Rev. George, D.D. Regius Professor of Divinity in the University of Dublin. *Trinity College, Dublin.*
1863. June 4.	P.	Salter, Samuel James Augustus, Esq., M.B. Lond. F.L.S. F.G.S. 17 *New Broad-street.* E.C.
1873. June 12.		Salvin, Osbert, Esq., M.A. F.L.S. F.Z.S. 32 *The Grove, Boltons.* S.W.
1864. June 2.		† Sanders, William, Esq., F.G.S. *Hanbury Lodge, The Avenue, Clifton.*
1867. June 6.	P.	Sanderson, J. S. Burdon, M.D. Coll. Reg. Med. Soc. Professor of Practical Physiology in University College, London. 49 *Queen-Anne-street.* W.
1833. Apr. 18.		† Saunders, Very Rev. Augustus Page, D.D. Dean of Peterborough. *Peterborough.*
1853. June 2.	P.	† Saunders, William Wilson, Esq., V.P.L.S. *Hill-field, Reigate.*
1858. June 3.	P.	Savory, William Scovell, Esq., M.B. 66 *Brook-street.* W.
1871. June 8.	P.	Schorlemmer, Carl, Esq., Lecturer on Organic Chemistry in Owens College, Manchester. *Owens College, Manchester.*
1850. June 6.	P.	† Schunck, Edward, Esq., F.C.S. *Oaklands, Kersall, Manchester.*
1861. June 6.		Sclater, Philip Lutley, Esq., M.A. F.L.S. Ph.D. (Bonn) Secretary of the Zoological Society. 11 *Hanover-square.* W.
1870. June 2.		† Scott, Robert Henry, Esq., M.A. F.G.S. Director of the Meteorological Office. *Meteorological Office,* 116 *Victoria-street; and* 36 *Onslow-square.* S.W.
1826. Dec. 7.		Scrope, George Poulett, Esq., F.G.S. *Fairlawn, Cobham, Surrey; and Castle-Comb-house, Chippenham.*
1860. June 7.		† Selborne, Roundell Palmer, Baron, Lord High Chancellor. 30 *Portland-place.* W.
1831. Jan. 13.		Selkirk, Thomas James, Earl of. *St. Mary's Isle, Kirkcudbright.*
1866. June 7.		† Selwyn, Rev. William, D.D. Margaret Professor of Divinity in the University of Cambridge, Canon of Ely, Chaplain in Ordinary to the Queen. *Vine-cottage, Cambridge.*
1861. June 6.		† Shadwell, Charles Frederick Alexander, Vice-Admiral, C.B. F.R.A.S. F.G.S. *Melksham, Wilts; and Hong Kong.*
1840. May 7.		† Sharp, William, M.D. F.G.S. *Horton-house, Rugby.*
1839. May 9.		Sharpey, William, M.D. LL.D.—Vice-President.—Professor of Anatomy and Physiology in University College, London, F.R.S.E. Acad. Monac. Soc. Reg. Sci. Gött. Soc. Phys. Med. Herbip. et Soc. Med. Suec. Socius, Acad. Sc. Nat. Philad., et Soc. Biol. Par. Corresp. 50 *Torrington-square; and University College.* W.C.
1860. June 21.		† Sheffield, George Augustus Frederick Charles Holroyd, Earl of, F.R.G.S. 58 *Portland-place,* W.; *and Sheffield-park, Uckfield, Sussex.*
1824. Mar. 11.		Shuckburgh, Sir Francis, Bart. *Pavilion, Hans-place, Chelsea,* S.W.; *and Shuckburgh-park, Warwickshire.*
1849. June 7.	P.	† Sibson, Francis, M.D. Coll. Reg. Med. Socius, Physician to St. Mary's Hospital. 59 *Brook-street.* W.
1862. June 5.	P.	Siemens, Charles William, Esq., D.C.L. (Oxon.) F.C.S. M.I.C.E. 3 *Great George-street, Westminster,* S.W.; *and* 3 *Palace-houses, Kensington-gardens.* W.

Date of Election.			
1845. Jan. 9.	P.		Simon, John, Esq., D.C.L. (Oxon.) F.R.C.S. Surgeon to St. Thomas's Hospital, Medical Officer of the Privy Council. 40 *Kensington-square.* W.
1862. June 5.	P.		Simpson, Maxwell, M.D. Hon. (Trin. Coll. Dubl.) A.B. V.P.C.S. Hon. F.K.Q.C.P. Dubl. Professor of Chemistry in Queen's College, Cork. *Queen's College, Cork.*
1841. June 10.			Smee, Alfred, Esq., F.R.C.S. F.C.S. 7 *Finsbury-circus.* E.C.
1860. June 7.	P.		Smith, Edward, M.D. LL.B. Coll. Reg. Med. Socius, Acad. Sci. et Lit. Montpellier, Soc. Hist. Nat. Montreal, Mem. Corr. 140 *Harley-street.* W.
1861. June 6.	P.		Smith, Henry John Stephen, Esq., M.A. F.C.S. Savilian Professor of Geometry in the University of Oxford. 64 *St. Giles's, Oxford.*
1837. June 1.			Smith, John T., Col. Madras Engineers. *Foelallt-house, Old Road, Lee.* S.E.
1841. Nov. 18.		†	Smith, Sir J. M. Frederic, Major-General, R.E. K.H. 9 *Hyde-park-square.* W.
1857. June 11.		†	Smith, Robert Angus, Esq., Ph.D. F.C.S. 22 *Devonshire-street, Manchester.*
1857. June 11.	P.		Smyth, Charles Piazzi, Esq., F.R.S.E. F.R.A.S. Astronomer Royal for Scotland, and Professor of Astronomy in the University of Edinburgh. 15 *Royal-terrace, Edinburgh.*
1858. June 3.			Smyth, Warington Wilkinson, Esq., M.A. V.P.G.S. Lecturer on Mining and Mineralogy at the Royal School of Mines, and Inspector of the Mineral Property of the Crown. *School of Mines,* S.W.; *and* 92 *Inverness-terrace, Bayswater.* W.
1864. June 2.		†	Smythe, William James, Major-General, R.A. M.R.I.A. *Athenæum Club.* S.W.
1843. Jan. 19.		†	Solly, Edward, Esq., F.S.A. F.L.S. F.G.S. *Sandecotes, near Poole.*
1845. June 5.			Sopwith, Thomas, Esq., M.A. F.G.S. 103 *Victoria-street, Westminster.* S.W.
1857. June 11.			Sorby, Henry Clifton, Esq., F.G.S. Soc. Min. Petrop. Soc. Batav. Sci. Harl. Socius. Acad. Sci. Nat. Philad. et Lyc. Hist. Nat. Nov. Ebor., Corr. Mem. *Broomfield, Sheffield.*
1853. June 2.	P.		Spottiswoode, William, Esq., M.A. LL.D.—TREASURER and VICE-PRESIDENT.—F.R.G.S. 50 *Grosvenor-place,* S.W.; *and Combe Bank, Sevenoaks.*
1856. June 5.			Spratt, Thomas A. B., Rear-Admiral, F.G.S. F.R.G.S. *Clare Lodge, Tunbridge Wells.*
1867. June 6.			Stainton, Henry Tibbats, Esq., Sec. L.S. F.G.S. *Mountsfield, Lewisham.* S.E.
1844. Feb. 1.		†	Stanford, John Frederick, Esq., M.A. *Forest Lodge, North Bank, Regent's-park.* N.W.
1827. Mar. 22.		†	Stanhope, Philip Henry, Earl, D.C.L. President of the Society of Antiquaries, Trust. Brit. Mus. 3 *Grosvenor-place-houses,* S.W.; *and Chevening-place, Sevenoaks, Kent.*
1863. June 4.			Stanley, The Very Rev. Arthur Penrhyn, D.D. Dean of Westminster, Inst. Fr. (Acad. Mor. et Polit.) Corresp. *Deanery, Westminster.* S.W.
1845. April 3.		†	Stebbing, Rev. Henry, D.D. F.R.B.S. Rector of St. Mary's Somerset, Upper Thames-street. *St. James's Parsonage, Hampstead-road.* N.W.
1848. June 9.	R. P.		Stenhouse, John, LL.D. V.P.C.S. 17 *Rodney-street, Pentonville.* N.
1832. April 5.		†	Stephens, Archibald John, Esq., Q.C. LL.D. Chancellor of the Dioceses of St. David's and Bangor, and Recorder of Winchester. 61 *Chancery-lane,* W.C.; *and St. James's, Windham, and Dublin University Clubs.*

Date of Election.			
1862. June 5.	Rm. P.		Stewart, Balfour, Esq., M.A. LL.D. (Edin.) Professor of Natural Philosophy in Owens College, Manchester. *Owens College, Manchester; and Lady Barn Villa, Fallowfield, Manchester.*
1838. May 3.			Stirling, Edward Hamilton, Esq. *Vauxhall, St. Helier's, Jersey.*
1851. June 5.	Rm. P.		Stokes, George Gabriel, Esq., M.A. D.C.L. LL.D. (Dubl.)—SECRETARY.—Lucasian Professor of Mathematics in the University of Cambridge. F.C.P.S. R. S. Edin. Soc. Reg. Hib. Lit. & Phil. Soc. Manc. et Med. Chi. Lond. Soc. Honor. Acad. Sci. Berol. Soc. Reg. Sci. Gött. Corresp. Soc. Reg. Sci. Upsal. et Soc Batav. Roterod. Socius. *Lensfield Cottage, Cambridge.*
1861. June 6.		†	Stokes, William, M.D. D.C.L. (Oxon. et Dunelm) LL.D. (Edin.) Regius Professor of Physic in the University of Dublin, Socc. Reg. Med. Edin. Path. et Epid. Lond. Imp. Med. Vindob. Inst. Nat. Philad. Soc. Honor. Socc. Med. Chi. Berol. Lips. Gand. Succ. et Soc. Med. Pub. Mag. Duc. Bad. Soc. Corr. et Soc. Med. Norv. Soc. Extr. 5 *Merrion-square, Dublin.*
1868. June 4.	P.	†	Stone, Edward James, Esq., M.A. F.R.A.S. Astronomer Royal at the Cape of Good Hope. *Cape Town.*
1861. June 6.		†	Stoney, George Johnstone, Esq., M.A. Secretary of the Queen's University of Ireland. *Weston, Dundrum, County Dublin.*
1854. June 1.		†	Strachey, Richard, Major-General R.E. C.S.I.—VICE-PRESIDENT.—F.G.S. F.R.G.S. F.L.S. *India Office,* S.W.; *and Stowey-house, Clapham-common.*
1841. May 6.		†	Strafford, George Stevens Byng, Earl of. 5 *St. James's-square,* S.W.; *and Harmondsworth.*
1864. June 2.		†	Strange, Alexander, Lieut.-Col. H.M.I.A. (retired), F.R.A.S. F.R.G.S., Inspector of Scientific Instruments to the Government of India. *India Store Depôt, Belvedere-road.* S.E.
1870. Nov. 24.			Sutherland, George Granville William Sutherland-Leveson Gower, Duke of, K.G. *Stafford-house,* S.W.; *Trentham-hall, Staffordshire; and Cliefden-house, Berkshire.*
1839. Apr. 25.	R. P.	†	Sylvester, James Joseph, Esq., M.A. LL.D. (Dubl. et Edin.) Inst. Fr. (Acad. Sci.) Par. Acad. Imp. Sci. Petrop. Reg. Sci. Berol. Soc. Reg. Sci. Gött. Ist. Lomb. Mediol. et Soc. Philom. Par. Mem. Corr. Soc. Reg. Sci. Neapol. Soc. Lit. et Phil. Manc. Soc. Honor. 60 *Maddox-street,* W.; *and Athenæum Club.* S.W.
1831. Mar. 17.			Talbot, Christopher Rice Mansel, Esq., F.L.S. 3 *Cavendish-square,* W.; *and Margam, Glamorganshire.*
1858. Feb. 18.			Talbot de Malahide, James, Lord, M.A. F.S.A. F.G.S. *Malahide-castle, Co. Dublin.*
1831. Mar. 17.	Rm. R. P.		Talbot, William Henry Fox, Esq., LL.D. F.L.S. *Lacock-abbey, near Chippenham.*
1845. Nov. 20.		†	Taylor, Alfred Swaine, M.D. Lecturer on Chemistry and Medical Jurisprudence at Guy's Hospital. 15 *St. James's-terrace, Regent's-park.* N.W.
1834. June 5.			Teignmouth, Charles John Shore, Lord, D.C.L. LL.D. *Langton-hall, Northallerton, Yorkshire.*
1869. June 3.		†	Tennant, James Francis, Lieut.-Colonel, R.E. F.R.A.S. & M.S. *Roorkee, N.W. Provinces, India.*
1865. June 1.		†	Tennyson, Alfred, Esq., D.C.L. (Oxon.) Poet Laureate, Soc. Reg. Edin. Soc. Honor. *Farringford, Freshwater, Isle of Wight.*

Date of Election.		
1871. June 8.		† Thomas, Edward, Esq., Treas. R.A.S. F.N.S. Hon. F.A.S. (Beng.) Inst. Fr. Acad. Inscrip. et Lit. Hum. et Soc. Antiq. Par. Corr. 47 *Victoria-road, Kensington.* W.
1848. June 9.		† Thomson, Allen, M.D. F.R.S.E. Professor of Anatomy in the University of Glasgow. *Glasgow.*
1855. June 7.		Thomson, Thomas, M.D. F.L.S. *The Cottage, West Farleigh, Maidstone.*
1851. June 5.	R P.	Thomson, Sir William, Knt., LL.D. Professor of Natural Philosophy in the University of Glasgow, Soc. Reg. Sci. Gött. Soc. Extr. *Glasgow.*
1869. June 3.	P.	Thomson, Wyville, Esq., LL.D. F.R.S. Edin. F.G.S. Regius Professor of Natural History in the University of Edinburgh. *H.M.S. 'Challenger.'*
1834. Apr. 10.		† Thornton, Henry Sykes, Esq., M.A. *Battersea-rise.* S.W.
1869. June 3.		† Thuillier, Henry Edward Landor, Colonel R.A. Surveyor-General of India. C.S.I. *Surveyor-General's Office,* 46 *Park-street, Calcutta.*
1865. June 1.		† Thwaites, George Henry Kendrick, Esq., F.L.S. Director of the Royal Gardens, Peradenia. *Peradenia, Ceylon.*
1862. June 5.		Todhunter, Isaac, Esq., M.A. *Bourne-house, Cambridge.*
1850. June 6.	P.	Tomes, John, Esq. Acad. Sci. Nat. Philad. Mem. Corr. 37 *Cavendish-square.* W.
1867. June 6.	P.	† Tomlinson, Charles, Esq., F.C.S. 3 *Ridgmount-terrace, Highgate.* N.
1842. Nov. 17.		Towneley, Charles, Esq., Trust. Brit. Mus. F.S.A. 12 *Charles-street, Berkeley-square.* W.
1866. June 7.		Townsend, Rev. Richard, M.A. Fellow of Trinity College and Professor of Natural Philosophy in the University of Dublin. *Trinity College, Dublin.*
1868. June 4.		Tristram, Rev. Henry Baker, M.A. (Oxon.) LL.D. F.L.S. M.Z.S. Master of Greatham Hospital, Canon of Durham. *Greatham Hospital, West Hartlepool.*
1845. Apr. 10.		† Tupper, Martin Farquhar, Esq., D.C.L. *Albury, Guildford, Surrey.*
1831. Mar. 17.		Turnbull, Rev. Thomas Smith, M.A. F.G.S. F.R.G.S. *Blofield, Norfolk.*
1838. Feb. 8.		† Tweedie, Alexander, M.D. Coll. Reg. Med. Socius. 6 *Pall Mall East,* S.W.; *and Bute Lodge, Park-road, Twickenham.*
1838. Mar. 15.		† Twiss, Sir Travers, Knt. Q.C. D.C.L. F.G.S. 3 *Paper-buildings, Temple.* E.C.
1871. June 8.		† Tylor, Edward Burnett, Esq. *Linden, Wellington, Somerset.*
1852. June 3.	Rm. P.	Tyndall, John, Esq., D.C.L. (Oxon.) LL.D. (Cantab.) F.C.P.S. Professor of Natural Philosophy in the Royal Institution, Soc. Lit. Phil. Manc. et Med.-Chi. Lond. Socius. Acadd. et Socc. Philomath. Par. Reg. Sci. Götting. Holland. Harl. Phys. et Nat. Hist. Genev. Nat. Ges. Tigur. Halæ. Marp. Vratisvl. Upsal. Nat. Scrutat. Berol. Socius. Ist. Reg. Lomb. Sci. et Lit. Soc. Met. Austr. et Reg. Sci. Upsal. Soc. Extr. *Royal Institution, Albemarle-street.* W.
1871. June 8.	P.	Varley, Cromwell Fleetwood, Esq., M.I.C.E. *Fleetwood House, Beckenham, Kent.*
1868. June 4.		† Vaux, William Sandys Wright, Esq., M.A. Pres. Numism. Soc. Hon. Sec. R.S.L. F.S.A. & R.G.S. M.R.A.S. 4 *Cheyne Walk, Chelsea.* S.W.
1870. June 2.		† Verdon, Sir George Frederic, Knt. C.B. K.C.M.G. *Melbourne, Australia.*
1855. June 7.		† Vignoles, Charles Blacker, Esq., V.P.I.C.E. F.R.A.S. M.R.I.A. 21 *Duke-street, Westminster.* S.W.
1870. June 2.		† Voelcker, Augustus, Esq., Ph.D. Professor of Chemistry to the Royal Agricultural Society of England. 39 *Argyll-road, Kensington.* W.
1826. June 8.		Vyvyan, Sir Richard Rawlinson, Bart. *Trelowarren, Helstone, Cornwall.*

Date of Election.		
1871. June 8.		† Walden, Arthur Viscount, Pres. Zool. Soc. *Walden Cottage, Chiselhurst.* S.E.
1855. June 7.	P.	† Walker, Charles Vincent, Esq., F.R.A.S. *Fernside, Red-hill, Reigate.*
1869. June 3.		† Walker, Edward, Esq., M.A. 2 *Cumberland-gate, Kew.* W.
1865. June 1.		Walker, James Thomas, Colonel R.E. *Dehra Doon, India.*
1860. Nov. 22.		† Walpole, The Right Hon. Spencer Horatio, M.A. D.C.L. Q.C. Trust. Brit. Mus. 109 *Eaton-square,* S.W.; *and Ealing.* W.
1835. Apr. 2.		† Warren, Samuel, Esq., D.C.L. Q.C. Master in Lunacy. 16 *Manchester-square.* W.
1834. Feb. 6.		Waterhouse, John, Esq. *Halifax, Yorkshire.*
1859. June 9.		† Watson, Sir Thomas, Bart., M.D. D.C.L. (Oxon.) Physician in Ordinary to the Queen, Coll. Reg. Med. Soc. 16 *Henrietta-street, Cavendish-square.* W.
1866. June 7.		Watts, Henry, Esq., B.A. F.C.S. 151 *King Henry's-road, South Hampstead.* N.W.
1858. June 3.		Waugh, Sir Andrew Scott, Knt. Major-General R.E. V.P.R.G.S. F.R.A.S. M.R.A.S. Soc. Geog. Berol. Assoc. Hon. Univ. Calcutt. Soc. 7 *Petersham-terrace, Queen's-gate-gardens,* W.; *and Athenæum Club.* S.W.
1845. June 5.		† Waveney, Robert Alexander Shafto Adair, Lord. 7 *Audley-square; and Flixton-hall, Bungay, Suffolk.*
1844. Mar. 7.		Webster, John, M.D. Coll. Reg. Med. Socius. 9 *Queen-street, St. Andrew's, Fife.*
1847. Mar. 18.		† Webster, Thomas, Esq., M.A. 2 *Pump-court, Temple.* E.C.
1840. Jan. 9.		Whatman, James, Esq., M.A. F.S.A. *Vinters, near Maidstone.*
1836. Jan. 21.	C. R. P.	Wheatstone, Sir Charles, D.C.L. (Oxon.), Ord. Boruss. "*Pour le Mérite*" Eq. Professor of Experimental Philosophy, King's College, London; Inst. Fr. (Acad. Sci.) Par. Acad. Sci. Berol. Corresp. Soc. Reg. Sci. Gött. et Acad. Sci. Monach. Soc. Extr. 19 *Park-crescent, Regent's-park.* N.W.
1854. June 1.		Whitbread, Samuel Charles, Esq., Treas. R.A.S. *Brewery, Chiswell-street,* E.C.; *and Cardington, Bedford.*
1857. June 11.		Whitworth, Sir Joseph, Bart., LL.D. *The Firs, Manchester; and Stancliffe-hall, Derbyshire.*
1834. Dec. 18.		Wilkinson, Sir John Gardner, Knt. D.C.L. F.R.G.S. Hon. Mem. R.S.L. R.I.B.A. et Ethn. Soc. Acadd. Imp. Reg. Sci. Vindob. et Reg. Sci. Taurin. Corresp. Or. Soc. Par. Ethn. Soc. Nov. Ebor. et Or. Soc. Bost. Soc. Honor. *Brynfield-house, Reynoldston, Glamorgan; and Athenæum Club.* S.W.
1870. June 2.		† Wilks, Samuel, M.D. Coll. Reg. Med. Soc. Lecturer on Medicine and Curator of the Museum, Guy's Hospital. 77 *Grosvenor-street.* W.
1862. June 5.	P.	Williams, C. Greville, Esq., F.C.S. *Rothesay Villa, Oxford-road, Turnham-green.* W.
1835. April 2.		† Williams, Charles James Blasius, M.D. Coll. Reg. Med. Soc. 49 *Upper Brook-street.* W.
1855. June 7.	R.	Williamson, Alexander William, Esq., Ph.D. V.P.C.S.—FOREIGN SECRETARY.—Professor of Chemistry and of Practical Chemistry, University College, London. Inst. Fr. (Acad. Sci.) Par. Corr. Mem. 23 *Fellows-road, Haverstock-hill.* N.W.
1854. June 1.	P.	Williamson, William Crawford, Esq., Professor of Natural History, Anatomy and Physiology, Owens College, Manchester. 4 *Egerton-road, Fallowfield, Manchester.*
1830. Apr. 22.		Willis, Rev. Robert, M.A. F.G.S. Jacksonian Professor of Natural and Experimental Philosophy in the University of Cambridge, Soc. Reg. Sci. Gött. Corresp. 5 *Park-terrace, Cambridge.*

Date of Election.			
1845. Feb. 6.	P.		Wilson, Erasmus, Esq., F.R.C.S. 17 *Henrietta-street, Cavendish-square.* W.
1855. June 7.			Wilson, George Fergusson, Esq., F.C.S. *Heatherbank, Weybridge-heath, Surrey.*
1845. Feb. 6.		†	Wilson, Rev. John, D.D. M.R.A.S. Hon. Pres. Bombay Branch of the R.A.S. *The Cliff, Malabar-hill, Bombay.*
1871. June 8.	P.		Wood, John, Esq., F.R.C.S. Professor of Surgery at King's College, London, Surgeon to King's College Hospital, Examiner in Anatomy at the University of London, and in Anatomy and Physiology at the University of Cambridge. 68 *Wimpole-street.* W.
1859. June 9.			Woodcroft, Bennet, Esq. *Great Seal Patent Office,* 25 *Southampton-buildings, Chancery-lane,* W.C.; *and* 30 *Redcliffe-gardens.* S.W.
1841. Apr. 29.		†	Woodward, Charles, Esq. 10 *Compton-terrace, Islington.* N.
1873. June 12.		†	Woodward, Henry, Esq., F.G.S. F.Z.S. Senior Assistant, Department of Geology, British Museum. 142 *St. Paul's-road, Camden-square.* N.W.
1859. June 9.		†	Yolland, William, Colonel R.E. F.R.A.S. 14 *St. Stephen's-square.* W.
1863. Feb. 19.		†	York, William Thomson, D.D., His Grace The Archbishop of. *The Palace, Bishopsthorpe, Yorkshire.*
1849. June 7.	P.	†	Yorke, Philip, Colonel, V.P.C.S. F.R.G.S. 89 *Eaton-place.* S.W.
1873. June 12.		†	Young, James, Esq., F.C.S. F.R.S.E. *Kelly, Wemyss-bay, near Greenock.*
1852. June 3.	P.	†	Younghusband, Charles Wright, Colonel R.A. *Waltham-abbey, Essex; and Athenæum Club.* S.W.

FOREIGN MEMBERS.

C.	Louis Agassiz	*Cambridge, U.S.*	1838.
Rm.	Anders Jonas Ångström	*Upsala.*	1870.
	Friedrich Wilhelm August Argelander	*Bonn.*	1846.
C.	Karl Ernst von Baer	*St. Petersburg.*	1854.
	J. B. A. L. L. Elie de Beaumont	*Paris.*	1835.
C.	Antoine César Becquerel	*Paris.*	1837.
	Claude Bernard	*Paris.*	1864.
	Theodor Ludwig Wilhelm von Bischoff	*Munich.*	1868.
	Adolphe Théodore Brongniart	*Paris.*	1852.
C.	Robert Wilhelm Bunsen	*Heidelberg.*	1858.
C.	Michel Chasles	*Paris.*	1854.
C.	Michel-Eugène Chevreul	*Paris.*	1826.
	Rudolph Julius Emmanuel Clausius	*Bonn.*	1868.
	Alphonse De Candolle	*Geneva.*	1869.
	Jean Bapt. J. D'Omalius d'Halloy	*Brussels.*	1873.
	Franz Cornelius Donders	*Utrecht.*	1866.
C.	Heinrich Wilhelm Dove	*Berlin.*	1850.
C.	Jean-Baptiste Dumas	*Paris.*	1840.
C.	Henry Milne-Edwards	*Paris.*	1848.
	Christian Gottfried Ehrenberg	*Berlin.*	1837.
	Georg Adolph Erman	*Berlin.*	1873.
	Asa Gray	*Cambridge, U.S.*	1873.
C.	Peter Andreas Hansen	*Seeberg.*	1835.
C.	Hermann Ludwig Ferdinand Helmholtz.	*Berlin.*	1860.
	Franz Gustav Jakob Henle	*Göttingen.*	1873.
	Charles Hermite	*Paris.*	1873.
	Albert Kölliker	*Würzburg.*	1860.
	Ernst Eduard Kummer	*Berlin.*	1863.
	Johann von Lamont	*Munich.*	1852.
C.	Urbain Jean Joseph Le Verrier	*Paris.*	1847.
	Joseph Liouville	*Paris.*	1850.
	Franz Ernst Neumann	*Königsberg.*	1862.
Rm.	Louis Pasteur	*Paris.*	1869.
	Benjamin Peirce	*Cambridge, U.S.*	1852.
	Joseph Antoine Ferdinand Plateau	*Ghent.*	1870.
	Philippe Gustave de Pontécoulant	*Paris.*	1833.
	Lambert Adolphe Jacques Quetelet	*Brussels.*	1839.
Rm. C.	Henri Victor Regnault	*Paris.*	1852.
	Otto August Rosenberger	*Halle.*	1835.
	Samuel Heinrich Schwabe	*Dessau.*	1868.
	Angelo Secchi	*Rome.*	1856.
	Karl Theodor von Siebold	*Munich.*	1858.
	Johannes Japetus Smith Steenstrup.	*Copenhagen.*	1863.
	Otto Wilhelm Struve	*Pulkowa.*	1873.
	Ernst Heinrich Weber	*Leipzig.*	1862.
C.	Wilhelm Eduard Weber	*Göttingen.*	1850.
C.	Friedrich Wöhler	*Göttingen.*	1854.
	Karl Adolph Würtz	*Paris.*	1864.

FELLOWS DECEASED SINCE THE LAST ANNIVERSARY (Nov. 30, 1872).

On the Home List.

Thomas Baring.
Richard Beamish.
John Bishop, F.R.C.S.
Lord Chief Justice Sir William Bovill.
Thomas Shaw Brandreth.
Charles Purton Cooper, LL.D.
Frederick Crace-Calvert, Ph.D.
Baldwin Francis Duppa, F.C.S.
John Edye, C.B.
Rev. George Fisher, M.A.
Charles Philip Yorke, Earl of Hardwicke, Vice-Admiral, D.C.L.
Sir Henry Holland, Bart., M.D., D.C.L.
Henry Bence Jones, M.D., D.C.L.
Robert MacAndrew, F.L.S.
John Robinson M^cClean, M.I.C.E.
Sir Frederick Madden, K.H.
Edward Latham Ormerod, M.D.
George Ormerod, D.C.L.
Prof. Richard Partridge.
William John Macquorn Rankine, LL.D.
Sir Francis Ronalds, Knt.
Rev. Canon Adam Sedgwick, M.A.
Archibald Smith, LL.D.
John Spencer Stanhope.
Paul Edmund Count de Strzelecki, C.B.
Sir William Tite, C.B.
Samuel Wilberforce, Lord Bishop of Winchester.

On the Foreign List.

Auguste De la Rive.
Christopher Hansteen.
Baron Justus von Liebig.
Hugo von Mohl. [illegible]
Gustav Rose.
Philippe Edouard Poulletier de Verneuil.

Change of Name and Title.

Sir Robert Alexander Shafto Adair	to	Lord Waveney.
The Hon. John William Strutt	to	Lord Rayleigh.

FELLOWS ELECTED SINCE THE LAST ANNIVERSARY (Nov. 30, 1872).

1873. Jan. 16.	† The Right Hon. Hugh Culling Eardley Childers.
1873. June 12.	† William Aitken, M.D.
1873. June 12.	† Sir Alexander Armstrong, M.D., K.C.B.
1873. June 12.	† Robert Stawell Ball, LL.D.
1873. June 12.	† John Beddoe, M.D.
1873. June 12.	† Frederick Joseph Bramwell, C.E.
1873. June 12.	† Captain Edward Killwick Calver, R.N.
1873. June 12.	† Robert Lewis John Ellery, F.R.A.S.
1873. June 12.	Lieut.-Col. J. Augustus Grant, C.B., C.S.I.
1873. June 12.	† Clements Robert Markham, C.B.
1873. June 12.	† George Edward Paget, M.D.
1873. June 12.	George West Royston-Pigott, M.D.
1873. June 12.	Osbert Salvin, M.A.
1873. June 12.	The Hon. John William Strutt, M.A.
1873. June 12.	† Henry Woodward, F.G.S.
1873. June 12.	† James Young, F.C.S.

On the Foreign List.

Baron Jean Baptiste Julien D'Omalius d'Halloy.
Georg Adolph Erman.
Asa Gray.
Franz Gustav Jakob Henle.
Charles Hermite.
Otto Wilhelm Struve.

NAMES OF PERSONS WHO HAVE RECEIVED THE MEDALS

OF

THE ROYAL SOCIETY.

COPLEY MEDAL.

1731. Stephen Gray.
1732. Stephen Gray.
1734. John Theophilus Desaguliers.
1736. John Theophilus Desaguliers.
1737. John Belchier.
1738. James Valoue.
1739. Stephen Hales.
1740. Alexander Stuart.
1741. John Theophilus Desaguliers.
1742. Captain Christophor Middleton.
1743. Abraham Trembley.
1744. Henry Baker.
1745. Sir William Watson.
1746. Benjamin Robins.
1747. Gowin Knight.
1748. Rev. James Bradley.
1749. John Harrison.
1750. George Edwards.
1751. John Canton.
1752. Sir John Pringle.
1753. Benjamin Franklin.
1754. William Lewis.
1755. John Huxham.
1757. Lord Charles Cavendish.
1758. John Dollond.
1759. John Smeaton.
1760. Benjamin Wilson.
1764. John Canton.
1766. William Brownrigg.
Edward Delaval.
Hon. Henry Cavendish.
1767. John Ellis.
1768. Peter Woulfe.
1769. William Hewson.
1770. Sir William Hamilton.
1771. Matthew Raper.
1772. Joseph Priestley.
1773. John Walsh.
1775. Rev. Nevil Maskelyne.
1776. Captain James Cook.
1777. John Mudge.
1778. Charles Hutton.
1780. Rev. Samuel Vince.
1781. Sir William Herschel.
1782. Richard Kirwan.
1783. John Goodricke.
Thomas Hutchins.
1784. Edward Waring.
1785. Major-General William Roy.
1787. John Hunter.
1788. Sir Charles Blagden.
1789. William Morgan.
1791. James Rennell.
John Andrew De Luc.
1792. Benjamin Count Rumford.
1794. Professor Volta.
1795. Jesse Ramsden.
1796. George Attwood.
1798. Sir George Shuckburgh Evelyn.
Charles Hatchett.
1799. Rev. John Hellins.
1800. Edward Howard.
1801. Sir Astley Paston Cooper.
1802. William Hyde Wollaston.
1803. Richard Chenevix.
1804. Smithson Tennant.
1805. Sir Humphry Davy.
1806. Thomas Andrew Knight.
1807. Sir Everard Home.
1808. William Henry.
1809. Edward Troughton.
1811. Benjamin Collins Brodie.
1813. William Thomas Brande.
1814. James Ivory.
1815. David Brewster.
1817. Captain Henry Kater.
1818. Sir Robert Seppings.
1820. John Christian Oersted.
1821. Captain Edward Sabine.
John Frederick William Herschel.
1822. Rev. William Buckland.
1823. John Pond.
1824. John Brinkley, Bishop of Cloyne.
1825. François Arago.
Peter Barlow.
1826. Sir James South.
1827. William Prout.
Captain Henry Foster.
1831. George Biddell Airy.
1832. Michael Faraday.
Baron Simeon Denis Poisson.
1834. Giovanni Plana.
1835. William Snow Harris.
1836. Jens Jacob Berzelius.
Francis Kiernan.
1837. Antoine C. Becquerel.
John Frederic Daniell.
1838. Karl Friedrich Gauss.
Michael Faraday.
1839. Robert Brown.
1840. Justus Liebig.
Jacques Charles François Sturm.
1841. George Simon Ohm.
1842. James MacCullagh.
1843. Jean Baptiste Dumas.
1844. Carlo Matteucci.
1845. Theodor Schwann.
1846. Urbain Jean Joseph Le Verrier.
1847. Sir John Frederick William Herschel.
1848. John Couch Adams.
1849. Sir Roderick Impey Murchison.
1850. Peter Andreas Hansen.
1851. Richard Owen.
1852. Baron Alexander von Humboldt.
1853. Heinrich Wilhelm Dove.
1854. Johannes Müller.
1855. Jean Bernard Leon Foucault.
1856. Henry Milne-Edwards.
1857. Michel Eugène Chevreul.
1858. Sir Charles Lyell.
1859. Wilhelm Eduard Weber.
1860. Robert Wilhelm Bunsen.

1861. Louis Agassiz.
1862. Thomas Graham.
1863. Rev. Adam Sedgwick.
1864. Charles Darwin.
1865. Michel Chasles.
1866. Julius Plücker.
1867. Karl Ernst von Baer.
1868. Sir Charles Wheatstone.
1869. Henri Victor Regnault.
1870. James Prescott Joule.
1871. Julius Robert Mayer.
1872. Friedrich Wöhler.
1873. Hermann Ludwig Ferdinand Helmholtz.

RUMFORD MEDAL.

1800. Benjamin Count Rumford.
1804. John Leslie.
1806. William Murdoch.
1810. Etienne Louis Malus.
1814. William Charles Wells.
1816. Sir Humphry Davy.
1818. David Brewster.
1824. Augustin Jean Fresnel.
1832. John Frederic Daniell.
1834. Macedonio Melloni.
1838. James David Forbes.
1840. Jean Baptiste Biot.
1842. Henry Fox Talbot.
1846. Michael Faraday.
1848. Henri Victor Regnault.
1850. François Jean Dominique Arago.
1852. George Gabriel Stokes.
1854. Neil Arnott.
1856. Louis Pasteur.
1858. Jules Jamin.
1860. James Clerk Maxwell.
1862. Gustav Robert Kirchhoff.
1864. John Tyndall.
1866. Armand Hippolyte Louis Fizeau.
1868. Balfour Stewart.
1870. Alfred Olivier Des Cloizeaux.
1872. Anders Jonas Ångström.

ROYAL MEDALS.

1826. John Dalton.
James Ivory.
1827. Sir Humphry Davy.
Friedrich Georg Wilhelm Struve.
1828. Johann Friedrich Encke.
William Hyde Wollaston.
1829. Charles Bell.
Eilhard Mitscherlich.
1830. David Brewster.
Antoine Jerome Balard.
1833. Auguste Pyrame De Candolle.
Sir John Frederick William Herschel.
1834. John William Lubbock.
Charles Lyell.
1835. Michael Faraday.
Sir William Rowan Hamilton.
1836. George Newport.
Sir John F. W. Herschel.
1837. Rev. William Whewell.
1838. Thomas Graham.
Henry Fox Talbot.
1839. James Ivory.
Dr. Martin Barry.
1840. Sir John F. W. Herschel.
Charles Wheatstone.
1841. Robert Kane.
Eaton Hodgkinson.
1842. William Bowman.
John Frederic Daniell.
1843. James David Forbes.
Charles Wheatstone.
1844. Thomas Andrews.
George Boole.
1845. George Biddell Airy.
Thomas Snow Beck.
1846. Michael Faraday.
Richard Owen.
1847. George Fownes.
William Robert Grove.
1848. Thomas Galloway.
Charles James Hargreave.
1849. Colonel Edward Sabine.
Gideon A. Mantell.
1850. Benjamin Collins Brodie.
Thomas Graham.
1851. Earl of Rosse.
George Newport.
1852. James Prescott Joule.
Thomas Henry Huxley.
1853. Charles Darwin.
1854. August Wilhelm Hofmann.
Joseph Dalton Hooker.
1855. John Russell Hind.
John Obadiah Westwood.
1856. Sir John Richardson.
William Thomson.
1857. Edward Frankland.
John Lindley..
1858. Albany Hancock.
William Lassell.
1859. George Bentham.
Arthur Cayley.
1860. William Fairbairn.
Augustus Waller.
1861. William B. Carpenter.
James Joseph Sylvester.
1862. Rev. Thomas Romney Robinson.
Alexander William Williamson.
1863. Rev. Miles J. Berkeley.
John Peter Gassiot.
1864. Jacob Lockhart Clarke.
Warren De La Rue.
1865. Joseph Prestwich.
Archibald Smith.
1866. William Huggins.
William Kitchen Parker.
1867. John Bennet Lawes and Joseph Henry Gilbert.
Sir William Logan.
1868. Alfred Russell Wallace.
Rev. George Salmon.
1869. Sir Thomas Maclear.
Augustus Matthiessen.
1870. William Hallowes Miller.
Thomas Davidson.
1871. John Stenhouse.
George Busk.
1872. Thomas Anderson.
Henry John Carter.
1873. George James Allman.
Henry Enfield Roscoe.

ADVERTISEMENT.

The Committee appointed by the *Royal Society* to direct the publication of the *Philosophical Transactions*, take this opportunity to acquaint the Public, that it fully appears, as well from the Council-books and Journals of the Society, as from repeated declarations which have been made in several former *Transactions*, that the printing of them was always, from time to time, the single act of the respective Secretaries till the Forty-seventh Volume; the Society, as a Body, never interesting themselves any further in their publication than by occasionally recommending the revival of them to some of their Secretaries, when, from the particular circumstances of their affairs, the *Transactions* had happened for any length of time to be intermitted. And this seems principally to have been done with a view to satisfy the Public that their usual meetings were then continued, for the improvement of knowledge and benefit of mankind, the great ends of their first institution by the Royal Charters, and which they have ever since steadily pursued.

But the Society being of late years greatly enlarged, and their communications more numerous, it was thought advisable that a Committee of their members should be appointed, to reconsider the papers read before them, and select out of them such as they should judge most proper for publication in the future *Transactions*; which was accordingly done upon the 26th of March 1752. And the grounds of their choice are, and will continue to be, the importance and singularity of the subjects, or the advantageous manner of treating them; without pretending to answer for the certainty of the facts, or propriety of the reasonings, contained in the several papers so published, which must still rest on the credit or judgment of their respective authors.

It is likewise necessary on this occasion to remark, that it is an established rule of the Society, to which they will always adhere, never to give their opinion, as a Body, upon any subject, either of Nature or Art, that comes before them. And therefore the thanks, which are frequently proposed from the Chair, to be given to the authors of such papers as are read at their accustomed meetings, or to the persons through whose hands they received them, are to be considered in no other light than as a matter of civility, in return for the respect shown to the Society by those communications. The like also is to be said with regard to the several projects, inventions, and curiosities of various kinds, which are often exhibited to the Society; the authors whereof, or those who exhibit them, frequently take the liberty to report, and even to certify in the public newspapers, that they have met with the highest applause and approbation. And therefore it is hoped that no regard will hereafter be paid to such reports and public notices; which in some instances have been too lightly credited, to the dishonour of the Society.

List of Public Institutions and Individuals entitled to receive a Copy of the Philosophical Transactions of each year, on making application for the same directly or through their respective agents, within five years of the date of publication.

Observatories.

Armagh.
Cape of Good Hope.
Dublin.
Edinburgh.
Greenwich.
Kew.
Liverpool.
Madras.
Oxford (Radcliffe).

Institutions.

Barbadoes	Library and Museum.
Birmingham	Free Central Library.
Calcutta	Asiatic Society.
	Geological Museum.
Cambridge	Philosophical Society.
Cape Town	South African Library.
Dublin	Royal Dublin Society.
	Royal Irish Academy.
Edinburgh	Royal Society.
London	Admiralty Library.
	Chemical Society.
	Entomological Society.
	Geological Society.
	Geological Survey of Great Britain.
	Institution of Civil Engineers.
	Institution of Naval Architects.
	Linnean Society.
	London Institution.
	Royal Asiatic Society.
	Royal Astronomical Society.
	Royal College of Physicians.
	Royal College of Surgeons.
	Royal Geographical Society.
	Royal Horticultural Society.
	Royal Institute of British Architects.
	Royal Institution of Great Britain.
	Royal Medical and Chirurgical Society.
	Royal Society of Literature.
	Society of Antiquaries.
	Society of Arts.
	The Queen's Library.
	The Treasury Library.
	The War Office.
	United Service Museum.
	Zoological Society.
Malta	Public Library.
Manchester	Literary and Philosophical Society.
Melbourne	University Library.
Montreal	M^c^Gill College.
Oxford	Ashmolean Society.
	Radcliffe Library.
Swansea	Royal Institution.
Sydney	University Library.
Woolwich	Royal Artillery Library.

America (South).

Buenos Ayres	Museo Publico.
Carácas	Sociedad di Ciencias Fisicas y Naturales.

Austria.

Brünn	Naturforschender Verein.
Gratz	Naturwissenschaftlicher Verein für Steiermark.
Innsbruck	Das Ferdinandeum.
Prague	Königlich böhmische Gesellschaft der Wissenschaften.
Vienna	Kaiserliche Akademie der Wissenschaften.
	Geographische Gesellschaft.
	Geologische Reichsanstalt.

Belgium.

Brussels	Académie Royale de Médecine.
	Académie Royale des Sciences.
Liége	Société des Sciences.
Louvain	L'Université.

Denmark.

Copenhagen	Kongelige Danske Videnskabernes Selskab.

Finland.

Helsingfors	Société des Sciences.

France.

Lyons	Académie des Sciences, Belles-Lettres et Arts.
Montpellier	Académie des Sciences et Lettres.
	Faculté de Médecine.
Paris	Académie des Sciences de l'Institut.
	Dépôt de la Marine.
	École des Mines.
	École Normale Supérieure.
	École Polytechnique.
	Faculté des Sciences de la Sorbonne.
	Jardin des Plantes.
	L'Observatoire.
	Société Entomologique.
	Société de Géographie.
	Société Géologique.
	Société d'Encouragement pour l'Industrie Nationale.
Toulouse	Académie des Sciences.

Germany.

Altona	Die Sternwarte.
Berlin	Die Sternwarte.

Berlin	Königliche Akademie der Wissenschaften.
	Physikalische Gesellschaft.
Danzig	Naturforschende Gesellschaft.
Dresden	Kaiserliche Leopoldino-Carolinische deutsche Akademie der Naturforscher.
Emden	Naturforschende Gesellschaft.
Frankfort-a-M.	Senckenbergische naturforschende Gesellschaft.
Giessen	Grossherzogliche Universität.
Göttingen	Königliche Gesellschaft der Wissenschaften.
Hamburg	Naturwissenschaftlicher Verein.
Heidelberg	Universität.
Jena	Medicinisch-Naturwissenschaftliche Gesellschaft.
Kiel	Universität.
Königsberg	Königliche-physikalisch-ökonomische Gesellschaft.
Leipzig	Königlich Sächsische Gesellschaft der Wissenschaften.
	Astronomische Gesellschaft.
Mannheim	Grossherzogliche Sternwarte.
Munich	Königlich-Bayerische Akademie der Wissenschaften.
Rostock	Universität.
Würzburg	Physikalisch-medicinische Gesellschaft.

Hungary.

Pesth	Á Magyar Tudós Társaság—Die Ungarische Akademie der Wissenschaften.

Italy.

Bologna	Accademia delle Scienze dell' Istituto.
Catanea	Accademia Gioenia di Scienze Naturali.
Florence	Reale Museo di Fisica.
Milan	Reale Istituto Lombardo di Scienze, Lettere ed Arti.
	Società Italiana di Scienze Naturali.
Modena	Società Italiana delle Scienze.
Naples	Società Reale, Accademia delle Scienze.
	Zoological Station (Dr. Dohrn).
Palermo	Reale Istituto Tecnico.
Rome	Accademia Pontificia de' Nuovi Lincei.
	Osservatorio del Collegio Romano.
Turin	Reale Accademia delle Scienze.
Venice	Reale Istituto Veneto di Scienze, Lettere ed Arti.

Java.

Batavia	Bataviaasch Genootschap van Kunsten en Wetenschappen.

Netherlands.

Amsterdam	Koninklijke Akademie van Wetenschappen.
Haarlem	Hollandsche Maatschappij der Wetenschappen.
Rotterdam	Bataafsch Genootschap der Proefondervindelijke Wijsbegeerte.

Portugal.

Coïmbra	University.
Lisbon	Academia Real das Sciencias.

Russia.

Kazan	Imperatorsky Kazansky Universitet.
Moscow	Société Impériale des Naturalistes.
	Le Musée Publique.
Pulkowa	Nikolai-Hauptsternwarte.
St. Petersburg	Académie Impériale des Sciences.

Spain.

Cadiz	Observatorio de S. Fernando.
Madrid	Real Academia de Ciencias.

Sweden and Norway.

Christiania	Kongelige Norske Frederiks Universitet.
Gottenburg	Kongl. Vetenskaps och Vitterhets Samhälle.
Lund	Universitet.
Stockholm	Kongliga Svenska Vetenskaps-Akademie.
	Bureau de la Recherche Géologique de la Suède.
Trondhjem	Kongelige Norske Videnskabers Selskab.
Upsala	Universitet.

Switzerland.

Bern	Allg. Schweizerische Gesellschaft.
Geneva	Société de Physique et d'Histoire Naturelle.
	Institut National Genevois.
Zürich	Das Schweizerische Polytechnikum.

Transylvania.

Hermannstadt	Siebenbürgischer Verein für die Naturwissenschaften.
Klausenburg	Az Erdélyi Muzeum—Das siebenbürgisches Museum.

United States.

Albany	New York State Library.
Boston	American Academy of Sciences.
	Boston Society of Natural History.
Cambridge	Harvard University.
Chicago	Academy of Sciences.
Newhaven (Conn.)	The Editors of the American Journal.
Philadelphia	Academy of Natural Sciences.
	American Philosophical Society.
Salem (Mass.)	Peabody Academy of Science.
Washington	Smithsonian Institution.
	U. S. Coast Survey.
	U. S. Naval Observatory.

The *fifty* Foreign Members of the Royal Society.

List of Public Institutions and Individuals entitled to receive a Copy of the Proceedings of the Royal Society.

laido	South Australian Institute.
ast	Queen's College.
ıbay	Geographical Society.
utta	Great Trigonometrical Survey of India.
	Meteorological Committee's Office.
ıbridge	Union Society.
k	Philosophical Society.
lin	Geological Society.
	Dublin University Zoological and Botanical Association.
dley	Dudley and Midland Geological and Scientific Society.
inburgh	Geological Society.
	Medical Society.
	Royal Physical Society.
	Royal Scottish Society of Arts.
way	Queen's College.
nilton, Canada West	Scientific Association.
art Town	Royal Society of Tasmania.
ds	Philosophical Society.
erpool	Historic Society of Lancashire and Cheshire.
	Literary and Philosophical Society.
ıdon	Anthropological Society.
	London Library.
	Mathematical Society.
	Meteorological Office.
	Meteorological Society.
	National Association for the Promotion of Social Science.
	Odontological Society.
	Pharmaceutical Society.
	Popular Science Review.
	Quarterly Journal of Science.
	Quekett Microscopical Club.
	Russell Institution.
	Standard Weights and Measures Department.
	Victoria Institute.
ıuritius	Royal Society of Arts and Sciences.
lbourne	Observatory.
	Royal Society of Victoria.
iddlesbrough	Iron and Steel Institute.
ontreal	Natural-History Society.
tley	Royal Victoria Hospital.
wcastle-upon-Tyne	Chemical Society.
	North of England Institute of Mining Engineers.
nzance	Geological Society of Cornwall.
ona	United Service Institution.
lford	Royal Museum and Library.
anghai	North China Branch of the Royal Asiatic Society.
ingapore	Journal of the Indian Archipelago.
Stonyhurst	The College.
Sydney (N.S.W.)	The Royal Society.
Windsor, Nova Scotia	King's College Library.

America (South).

New Granada	Société des Naturalistes.

Austria.

Innsbruck	Naturwissenschaftlich-Medicinischer Verein.
Prague	Spolek Chemikův Českých (Bohemian Chemical Society).
Schemnitz	K. Ungarische Berg. und Först Akademie.
Vienna	Anthropologische Gesellschaft.
	Œsterreichische Gesellschaft für Meteorologie.
	Zoologisch-Botanische Gesellschaft.

Belgium.

Luxembourg	Société des Sciences Naturelles.

France.

Apt (Vaucluse)	Société Littéraire, Scientifique et Artistique.
Bordeaux	Académie des Sciences.
	Faculté des Sciences.
	Société des Sciences Physiques et Naturelles.
	Société Medico-Chirurgicale.
Cherbourg	Société des Sciences Naturelles.
Dijon	Académie des Sciences.
Paris	Société de Biologie.
	Société Météorologique de France.
	Cosmos (Mons. Victor Meunier).
	Les Mondes (Mons. l'Abbé Moigno).
	Revue des Cours Scientifiques (Mons. Alglave).

Germany.

Bremen	Naturwissenschaftlicher Verein.
Breslau	Schlesische Gesellschaft für Vaterländische Kultur.
Dresden	Verein für Erdkunde.
Frankfurt-a-M.	Zoologische Gesellschaft.
Freiburg im Breisgau	Naturforschende Gesellschaft.
Görlitz	Naturforschende Gesellschaft.
Göttingen	Zeitschrift für Chemie (Beilstein, Fittig & Hübner).
Halle	Naturwissenschaftlicher Verein für Sachsen und Thüringen.
Heidelberg	Naturhistorisch-Medizinische Gesellschaft.
Munich	Zeitschrift für Biologie.

Italy.

Bologna	Archivio per la Zoologia, &c. (Richiard & Canestrini).
Florence	R. Comitato Geologico d'Italia.

Siena	R. Accademia de' Fisiocritici.
Venice	Ateneo Veneto.

Netherlands.

Amsterdam	K. Zoologisch Genootschap Natura Artis Magistra.
Utrecht	Provinciaal Genootschap van Kunsten en Wetenschappen.

Russia.

St. Petersburg	Compass Observatory.

Switzerland.

Basel	Naturforschende Gesellschaft.
Bern	Naturforschende Gesellschaft.
Lausanne	Société Vaudoise des Sciences Naturelles.
Neuchâtel	Société des Sciences Naturelles.
Zürich	Naturforschende Gesellschaft.

United States.

Boston	Gynaecological Society.
Buffalo	Medical and Surgical Journal.
Charleston	Elliott Society of Natural History of South Carolina.
Louisville	Richmond and Louisville Medical Journal.
New Yerk	American Geographical and Statistical Society.
	American Journal of Obstetrics.
	Lyceum of Natural History.
	Medical Gazette.
	Medical Journal.
	School of Mines, Columbia College.
Ohio	Kenyon College.
Philadelphia	Franklin Institute.
St. Louis	Academy of Science.
Salem (Mass.)	Essex Institute.
Vermont	Orleans County Society of Natural History.
Virginia	Medical Society.
Washington	Department of Agriculture.

Individuals.

Costa, Cavalier Achille	Naples.
Kronig, Dr.	Berlin.
Lees, Hon. Chief Justice	Nassau, New Providence, Bahamas.
Poggendorff, Professor	Berlin.
Tortolini, Signor B.	Rome.
Wartmann, Professor Elie	Geneva.
Wolf, Professor R.	Zurich.

PHILOSOPHICAL
TRANSACTIONS
OF THE
ROYAL SOCIETY
OF
LONDON.

FOR THE YEAR MDCCCLXXIII.

VOL. 163.—PART I.

LONDON:
PRINTED BY TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET.
MDCCCLXXIII.

CONTENTS.

PART I.

I. *The Diurnal Variations of the Wind and Barometric Pressure at Bombay. By* F. CHAMBERS. *Communicated by* CHARLES CHAMBERS, *F.R.S., Director of the Colaba Observatory, Bombay* . . . . page 1

I*. *On the Osteology of the* Hyopotamidæ. *By Dr.* W. KOWALEVSKY. *Communicated by Professor* HUXLEY, *Sec. R.S.* 19

II. THE BAKERIAN LECTURE.—*On the Structure and Development of the Skull in the Salmon* (Salmo salar, *L.*). *By* WILLIAM KITCHEN PARKER, *F.R.S.* . . . 95

III. *Volcanic Energy: an attempt to develop its true Origin and Cosmical Relations. By* ROBERT MALLET, *A.M., C.E., M.R.I.A., F.R.S.* 147

IV. *On Curvature and Orthogonal Surfaces. By* A. CAYLEY, *LL.D., F.R.S., Sadlerian Professor of Mathematics in the University of Cambridge* 229

V. *Researches in Spectrum-Analysis in connexion with the Spectrum of the Sun.*—No. I. *By* J. NORMAN LOCKYER, *F.R.S.* 253

VI. *Researches on the Atomic Weight of Thallium. By* WILLIAM CROOKES, *F.R.S., &c.* 277

VII. *Magnetical Observations in the Britannia and Conway Tubular Iron Bridges. By Sir* GEORGE BIDDELL AIRY, *K.C.B., P.R.S., Astronomer Royal* 331

VIII. *Magnetic Survey of Belgium in* 1871. *By the Rev.* STEPHEN J. PERRY. *Communicated by General Sir* EDWARD SABINE, *F.R.S.* 341

IX. *On the Union of Ammonia Nitrate with Ammonia. By* EDWARD DIVERS, *M.D. Communicated by* Professor ODLING, *M.B., F.R.S.* 359

X. *On the Organization of the Fossil Plants of the Coal-measures.*—Part IV. Dictyoxylon, Lyginodendron, *and* Heterangium. *By* W. C. WILLIAMSON, *F.R.S.*, *Professor of Natural History in Owens College, Manchester* . . . page 377

XI. *Determination of the Number of Electrostatic Units in the Electromagnetic Unit made in the Physical Laboratory of Glasgow University. By* DUGALD M'KICHAN, *M.A. Communicated by Sir* WILLIAM THOMSON, *F.R.S. &c.* 409

XII. *On the Minute Structure of the Leg-muscles of the Water-beetle. By* EDWARD ALBERT SCHÄFER. *Communicated by* DR. SHARPEY, *V.P.R.S.* 429

LIST OF ILLUSTRATIONS.

Plates XLI. to XLVII.—Report on the Exploration of Brixham Cave.

Plate XLVIII.—The Earl of Rosse on the Radiation of Heat from the Moon.

Plates XLIX. & L.—Dr. Rudolph von Willemöes-Suhm on a new Genus of Amphipod Crustaceans.

Plates LI. & LII.—Mr. J. Norman Lockyer on Spectrum-Analysis in connexion with the Spectrum of the Sun.

PHILOSOPHICAL TRANSACTIONS

OF THE

ROYAL SOCIETY

OF

LONDON.

FOR THE YEAR MDCCCLXXIII.

VOL. 163.—PART II.

LONDON:
PRINTED BY TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET.
MDCCCLXXIV.

CONTENTS.

PART II.

XIII. *Results of the Comparisons of the Standards of Length of England, Austria, Spain, United States, Cape of Good Hope, and of a second Russian Standard, made at the Ordnance Survey Office, Southampton. By Lieutenant-Colonel* A. R. Clarke, *C.B., R.E., F.R.S., &c., under the direction of Major-General Sir* Henry James, *R.E., F.R.S., &c., Director-General of the Ordnance Survey. With a Preface and Notes on the Greek and Egyptian Measures of Length by Sir* Henry James . . . . page 445

XIV. *Report on the Exploration of Brixham Cave, conducted by a Committee of the Geological Society, and under the superintendence of* Wm. Pengelly, *Esq., F.R.S., aided by a local Committee; with Descriptions of the Animal Remains by* George Busk, *Esq., F.R.S., and of the Flint Implements by* John Evans, *Esq., F.R.S. By* Joseph Prestwich, *F.R.S., F.G.S., &c., Reporter* 471

XV. *On a new Locality of Amblygonite, and on Montebrasite, a new Hydrated Aluminium and Lithium Phosphate. By* M. A. O. Des Cloizeaux, *Member of the Institute of France. Communicated by Professor* W. H. Miller, *Foreign Secretary R.S.* 573

XVI. The Bakerian Lecture.—*On the Radiation of Heat from the Moon, the Law of its Absorption by our Atmosphere, and of its Variation in Amount with her Phases. By the* Earl of Rosse, *B.A., D.C.L., F.R.S.* 587

XVII. *On a new Genus of Amphipod Crustaceans. By* Rudolph von Willemöes-Suhm, *Ph.D., Naturalist to the 'Challenger' Exploring-Expedition. Communicated by Dr.* Wyville Thomson, *F.R.S.* 629

XVIII. *Researches in Spectrum-Analysis in connexion with the Spectrum of the Sun.—* No. II. *By* J. Norman Lockyer, *F.R.S.* 639

Index 659

ADJUDICATION of the MEDALS of the ROYAL SOCIETY for the year 1873 by the PRESIDENT and COUNCIL.

The COPLEY MEDAL to Professor HERMANN LUDWIG FERDINAND HELMHOLTZ, For. Memb. R.S., for his Researches in Physics and Physiology.

A ROYAL MEDAL to Professor GEORGE JAMES ALLMAN, F.R.S., for his Researches in Zoology, and especially for his Memoirs on the Structure, Development, and Physiology of the Gymnoblastic Hydroids.

A ROYAL MEDAL to Professor HENRY ENFIELD ROSCOE, F.R.S., for his various Chemical Investigations, especially for those on the Chemical Action of Light, and upon the element Vanadium and its combinations.

The BAKERIAN LECTURE was delivered by the EARL OF ROSSE, F.R.S.: it was entitled "On the Radiation of Heat from the Moon, the Law of its Absorption by our Atmosphere, and its Variation in Amount with her Phases."

The CROONIAN LECTURE was delivered by BENJAMIN WARD RICHARDSON, M.D., F.R.S.: it was entitled "On Muscular Irritability after Systemic Death."

PHILOSOPHICAL TRANSACTIONS.

I. *The Diurnal Variations of the Wind and Barometric Pressure at Bombay. By* F. CHAMBERS. *Communicated by* CHARLES CHAMBERS, *F.R.S., Director of the Colaba Observatory, Bombay.*

Received May 27,—Read June 19, 1873.

1. THE object of this paper is to draw attention to a remarkable relation which has been found to exist between the diurnal variation of the wind and the double diurnal oscillation of the barometer at Bombay, and which, it is believed, will be of great interest to all meteorologists.

2. The observations made use of in the discussion are the hourly tabulations from the record of a ROBINSON'S Anemograph from June 1867 to May 1870, the hourly observations of the barometer and temperature of the air for the same period, and the corresponding pressure of vapour (calculated from the readings of the dry- and wet-bulb thermometers), and also some particular results of later date which will be introduced in the course of the inquiry. A full description of the various instruments and the methods of observation and reduction is given in the introduction to the "Bombay Magnetical and Meteorological Observations, 1865–70;" but it may be well briefly to recapitulate here the method of reducing the anemograph indications, as it is entirely owing to its mathematical exactness that the results now brought forward have been obtained, and it is therefore deserving of special attention.

The wind of every hourly interval is resolved into a north or south wind and an east or west wind of such velocities, that, if they blew together, the resulting movement and direction would be the same as is actually observed. The formulæ by which these resolutions are effected are:—

Velocity of wind from north or south $=m \cos (n \times 22\frac{1}{2}$ degrees) . . . . . (1)

Velocity of wind from east or west $=m \sin (n \times 22\frac{1}{2}$ degrees). . . . . . (2)

Where m is the movement observed and n the number of the direction-space under which the wind of the hourly interval is classed, the circle being divided into sixteen spaces, which are numbered consecutively from 0 to 15, and correspond respectively to the directions N., N.N.E., N.E., &c.; hence the quantity calculated from (1) will represent either a north or a south wind, according as its sign is positive or negative, and similarly for the east or west wind calculated from (2). The algebraical averages of the north and south and of the east and west component winds may then be taken separately for any given period, and these will, when combined, truly represent the average velocity and direction of the wind for that period. Such averages have been calculated for each hour of the day in the whole period from June 1867 to May 1870, or three complete years. They are given in the following Table, along with the corresponding averages of most of the other meteorological elements.

Table I.—Mean Values of Meteorological Elements for each hour of the day from May 1867 to June 1870, and their Mean Diurnal Variations for the same period.

Bombay Civil Hours.	Wind.				Bombay Civil Hours.	Barometer pressure. Reduced to 32° F.		Pressure of vapour.		Pressure of dry air.		Temperature of air.	
	Mean N. or S. component.	Variation of N. or S. component.	Mean E. or W. component.	Variation of E. or W. component.		Mean.	Variation.	Mean.	Variation.	Mean.	Variation.	Mean.	Variation.
0 to 1	1·03 N.	1·04 S.	4·46 W.	1·79 E.	0	29·824	+0·004	0·781	−0·002	29·043	+·006	77°·3	−2°·1
1 ,, 2	1·07 N.	1·00 S.	3·96 W.	2·29 E.	1	·810	− ·010	·777	− ·006	·033	−·004	76·9	−2·5
2 ,, 3	0·93 N.	1·14 S.	3·56 W.	2·69 E.	2	·797	− ·023	·773	− ·010	·024	−·013	76·7	−2·7
3 ,, 4	1·10 N.	0·97 S.	3·09 W.	3·16 E.	3	·791	− ·029	·768	− ·015	·023	−·014	76·3	−3·1
4 ,, 5	1·27 N.	0·80 S.	2·52 W.	3·73 E.	4	·793	− ·027	·762	− ·021	·031	−·006	76·1	−3·3
5 ,, 6	1·27 N.	0·80 S.	1·96 W.	4·29 E.	5	·804	− ·016	·756	− ·027	·048	+·011	75·8	−3·6
6 ,, 7	1·00 N.	1·07 S.	1·19 W.	5·06 E.	6	·822	+ ·002	·754	− ·029	·068	+·031	75·7	−3·7
7 ,, 8	0·73 N.	1·34 S.	0·86 W.	5·39 E.	7	·844	+ ·024	·760	− ·023	·084	+·047	76·4	−3·0
8 ,, 9	0·77 N.	1·30 S.	1·09 W.	5·16 E.	8	·864	+ ·044	·767	− ·016	·097	+·060	77·9	−1·5
9 ,, 10	0·67 N.	1·40 S.	2·16 W.	4·09 E.	9	·877	+ ·057	·772	− ·011	·105	+·068	79·4	0·0
10 ,, 11	0·43 N.	1·64 S.	4·39 W.	1·86 E.	10	·876	+ ·056	·774	− ·009	·102	+·065	80·7	+1·3
11 ,, 12	0·83 N.	1·24 S.	7·12 W.	0·87 W.	11	·862	+ ·042	·777	− ·006	·085	+·048	82·0	+2·6
12 ,, 13	1·67 N.	0·40 S.	9·92 W.	3·67 W.	12	·839	+ ·019	·783	·000	·056	+·019	83·2	+3·8
13 ,, 14	2·09 N.	0·02 N.	11·39 W.	5·14 W.	13	·816	− ·004	·795	+ ·012	·021	−·016	84·0	+4·6
14 ,, 15	3·17 N.	1·10 N.	12·72 W.	6·47 W.	14	·793	− ·027	·805	+ ·022	28·988	−·049	84·3	+4·9
15 ,, 16	3·93 N.	1·86 N.	12·99 W.	6·74 W.	15	·778	− ·042	·807	+ ·024	·971	−·066	84·3	+4·9
16 ,, 17	4·70 N.	2·63 N.	12·66 W.	6·41 W.	16	·773	− ·047	·811	+ ·028	·962	−·075	83·7	+4·3
17 ,, 18	4·83 N.	2·76 N.	11·59 W.	5·34 W.	17	·778	− ·042	·803	+ ·020	·975	−·062	82·1	+2·7
18 ,, 19	4·87 N.	2·80 N.	10·02 W.	3·77 W.	18	·791	− ·029	·802	+ ·019	·989	−·048	80·4	+1·0
19 ,, 20	4·40 N.	2·33 N.	8·39 W.	2·14 W.	19	·809	− ·011	·800	+ ·017	29·009	−·028	79·5	+0·1
20 ,, 21	3·43 N.	1·36 N.	7·32 W.	1·07 W.	20	·826	+ ·006	·800	+ ·017	·026	−·011	79·0	−0·4
21 ,, 22	2·47 N.	0·40 N.	6·36 W.	0·11 W.	21	·839	+ ·019	·795	+ ·012	·044	+·007	78·5	−0·9
22 ,, 23	1·73 N.	0·34 S.	5·52 W.	0·73 E.	22	·842	+ ·022	·787	+ ·004	·055	+·018	78·0	−1·4
23 ,, 0	1·20 N.	0·87 S.	4·76 W.	1·49 E.	23	·835	+ ·015	·782	− ·001	·053	+·016	77·5	−1·9
	2·07 N.	......	6·25 W.			29·820	......	0·783	......	29·037	......	79·4	

The observations of the barometer and thermometers were made seven minutes and five minutes respectively after the full hour.

These variations are also represented graphically by figures 1, 2, 3, 4 and 5, Plate XXXIV.

3. From the hourly values of the variation of the barometer given above, the constants in the first three terms of the right-hand member of Bessel's formula,

$$E = B_1 \sin(\theta + C_1) + B_2 \sin(2\theta + C_2) + B_3 \sin(3\theta + C_3) + \&c., \quad .. \quad . \quad .. \quad (3)$$

have been calculated and found to be

$$B_1 = \cdot 0179, \qquad C_1 = 337^{\circ}\ 17',$$
$$B_2 = \cdot 0385, \qquad C_2 = 157\ \ 13,$$
$$B_3 = \cdot 0014, \qquad C_3 = \ 25\ \ \ 0;$$

and from these values we find that the maxima and minima and the times of their occurrence are as follows, viz. :—

		h	m
The first minimum in the day . .	=−·0293 at	3	29
,, ,, maximum ,, ,, . .	=+·0551 ,,	9	32
,, second minimum ,, ,, . .	=−·0484 ,,	16	1
,, ,, maximum ,, ,, . .	=+·0228 ,,	22	5

Now marking these times along the course of the wind-curve (fig. 1), we see that they and the centre of the curve are all of them almost exactly in the same straight line—that the straight line being drawn through the centre so as to pass as close as possible to each of the marks so laid down divides the curve into four branches, two turned to the north of the line and two turned to the south of it—and that the direction of the line itself is the same as the general direction of the whole curve. We now see that the curve is such a one as would be formed by two distinct variations being superimposed the one on the other—one, the movement in the direction of the line, having a single period like the temperature-curve (fig. 5), and the other, the north and south movement, having a double period, and in this respect like the barometer-curve (fig. 2), but differing from it in that it passes through its mean positions at the four times when the latter is at its extreme positions, and *vice versâ.* A closer comparison of the two curves (1 and 2) shows that when the wind-curve passes to the north of the line A B, the barometer begins to rise, and the more rapidly the further the curve departs from the line, and ceases to do so on the return of the curve back to the line; similarly the barometer falls when the curve passes to the south of the line, its rate of descent being approximately proportional to the distance of departure of the wind-curve from the line.

4. There can be no doubt that the greater part of the more extensive east and west movement is the land- and sea-breeze; and this feature and the generally accepted theory which explains it have been already commented upon in Appendix I. of the Bombay Magnetical and Meteorological Observations for 1865 to 1870, on "The Normal Winds of Bombay." The explanation of the double diurnal variation which we find is superimposed at Bombay on the land- and sea-breeze is not, however, so apparent; and before a complete view of the nature of this variation could be obtained, it would be necessary to eliminate from the whole curve that part which may be considered due to the pure land- and sea-breeze; but the precise nature of this part is itself unknown, and the elimination could only be effected by a comparison of the curve for Bombay with that of some other place, where, other conditions being similar, the land- and sea-breeze is either entirely absent or reversed in direction, as, for instance, at Madras; but similar results for such a place are not yet available, and an approximate view is all that can be afforded at present.

5. The principal features of the pure land- and sea-breeze will be more clearly exhibited in the following manner. Assuming that its direction is completely represented by the straight line A B, fig. 1, which is inclined to the east and west line at an angle

of $18\frac{1}{2}^\circ$, then all the hourly points being projected in a north or south direction upon this line will give a series of points which will represent the variation of the land- and sea-breeze combined with any of the diurnal variation which may exist in the same direction, similar to that which does exist in a north and south direction. The variation is given below, and has been obtained by multiplying the east components of the variation of the wind for each hour, given in Table I., by secant $18\frac{1}{2}^\circ$.

TABLE II.—Mean Land- and Sea-Breeze at Bombay.

Bombay Civil Hours	0 to 1.	1–2.	2–3.	3–4.	4–5.	5–6.	6–7.	7–8.
Velocity of wind in miles per hour	E.S.E. 1·89	E.S.E. 2·41	E.S.E. 2·84	E.S.E. 3·33	E.S.E. 3·93	E.S.E. 4·52	E.S.E. 5·33	E.S.E. 5·68
Bombay Civil Hours	8 to 9.	9–10.	10–11.	11–12.	12–13.	13–14.	14–15.	15–16.
Velocity of wind in miles per hour	E.S.E. 5·44	E.S.E. 4·31	E.S.E. 1·96	W.N.W. 0·92	W.N.W. 3·87	W.N.W. 5·42	W.N.W. 6·82	W.N.W. 7·10
Bombay Civil Hours	16 to 17.	17–18.	18–19.	19–20.	20–21.	21–22.	22–23.	23–0.
Velocity of wind in miles per hour	W.N.W. 6·76	W.N.W. 5·63	W.N.W. 3·97	W.N.W. 2·26	W.N.W. 1·13	W.N.W. 0·12	E.S.E. 0·77	E.S.E. 1·57

It is also represented graphically by fig. 6, which will be seen to be remarkably like the temperature-curve (fig. 5) in general character, but from about 1 to 2 hours later in phase. This general resemblance is satisfactorily explained by the theory already adverted to; for the producing cause of the land- and sea-breeze, according to that theory, being the difference of temperature indicated by two temperature-curves, viz. that of the land and that of the sea (which presumably differ from each other only in extent and not in form), will also be represented by a temperature-curve of a like nature; and it is to be expected therefore that the land- and sea-breeze, when represented as in fig. 6, will have some such resemblance to the temperature-curve as that which it exhibits. But fig. 6 has at the same time very definite and distinctive features peculiar to itself; amongst these may be mentioned:—

1st. Its rapid transition from east to west, moving from $10\frac{1}{2}$ hours to $12\frac{1}{2}$ hours through nearly half of its whole range, which is much more rapid than the corresponding change of the temperature-curve.

2nd. From 18 hours to 6 hours the curve is first convex and afterwards slightly concave downwards, having a point of inflection about midnight, while the temperature-curve is convex downwards during the whole of the same interval.

These features are what might be expected from the superposition on the land- and sea-breeze of an east and west double diurnal variation of the wind which attains its maximum east positions at about the same hours at which the barometer reaches its maxima, and attains its maximum west positions at about the same hours at which the barometer reaches its minima, and passes through zero at the times when the barometer passes through its mean positions. A strong reason for believing that these features are produced by the superposition of such a variation, is afforded by the mean diurnal variation of the east or west components of the wind for the months of July and August alone; for during these months the land- and sea-breeze has almost entirely disappeared, because the difference between the daily ranges of temperature of the land and sea is then very small, and the wind variation then found is of the kind here described, and would, when superimposed upon the mean temperature-curve for the year, produce a curve having similar features to those enumerated as peculiar to the curve which represents the land- and sea-breeze. The variation is given in Table III., and also graphically represented by fig. 7.

Table III.—Mean velocities of the north or south and east or west components of the wind at Bombay for each hour of the day in the months of July and August 1867 to 1870; also the mean diurnal variations for the same period.

Bombay Civil Hours	0 to 1.	1–2.	2–3.	3–4.	4–5.	5–6.	6–7.	7–8.
N. or S. component	5·67 s.	5·47 s.	5·33 s.	5·33 s.	4·85 s.	4·36 s.	4·43 s.	4·87 s.
Variation	1·02 s.	0·82 s.	0·68 s.	0·68 s.	0·20 s.	0·29 n.	0·22 n.	0·22 s.
E. or W. component	15·64 w.	16·11 w.	16·03 w.	16·07 w.	15·80 w.	15·78 w.	14·72 w.	14·90 w.
Variation	0·47 e.	0·00	0·08 e.	0·04 e.	0·31 e.	0·33 e.	1·39 e.	1·21 e.
Bombay Civil Hours	8–9.	9–10.	10–11.	11–12.	12–13.	13–14.	14–15.	15–16.
N. or S. component	4·42 s.	4·51 s.	4·97 s.	4·77 s.	4·39 s.	4·19 s.	4·41 s.	3·97 s.
Variation	0·23 n.	0·14 n.	0·32 s.	0·12 s.	0·26 n.	0·46 n.	0·24 n.	0·68 n.
E. or W. component	14·81 w.	14·98 w.	15·76 w.	16·44 w.	17·42 w.	17·39 w.	17·90 w.	17·99 w.
Variation	1·30 e.	1·13 e.	0·35 e.	0·33 w.	1·31 w.	1·28 w.	1·79 w.	1·79 w.
Bombay Civil Hours	16–17.	17–18.	18–19.	19–20.	20–21.	21–22.	22–23.	23–0.
N. or S. component	3·71 s.	3·78 s.	3·90 s.	4·29 s.	4·57 s.	4·86 s.	5·26 s.	5·29 s.
Variation	0·94 n.	0·87 n.	0·75 n.	0·36 n.	0·08 n.	0·21 s.	0 61 s.	0·64 s.
E. or W. component	17·71 w.	17·31 w.	16·41 w.	15·66 w.	16·25 w.	15·23 w.	15·33 w.	15·00 w.
Variation	1·60 w.	1·20 w.	0·30 w.	0·45 e.	0·14 w.	0·88 e.	0·78 e.	1·11 e.

The mean components for the whole period are 46·5 S. and 16·11 W.

During these two months the south-west monsoon is at its height at Bombay, and the wind is more boisterous and irregular in strength, though not in direction, than at any other part of the year; the observations are consequently insufficient to give a very regular curve, but it is sufficiently regular to justify conclusions being drawn from its more salient features. The smoothed curve has been calculated from the original one by means of the first three terms of Bessel's formula. It clearly exhibits a *double* period like the north and south variation and like the barometer variation, and (remembering that no attempt has been made to eliminate the portion of the land- and sea-breeze which probably still remains) its general resemblance when inverted to the barometer-curve (fig. 2) is very remarkable. The part of this variation which contains the double period, and which will be supposed independent of the land- and sea-breeze, will hereafter be called the *longitudinal* diurnal variation of the wind, to distinguish it from the whole east and west movement given in Table I., and from the pure land- and sea-breeze.

6. If we again make the same assumption as before, regarding the nature of the land- and sea-breeze, viz. that its direction is completely represented by the line A B (fig. 1), its effect in modifying the north and south double diurnal variation of the wind may be approximately eliminated by measuring the north and south components from the line A B as the datum line, instead of from the east and west line. This has been done by means of the expression

North component of double diurnal wind variation = north component of whole wind variation as given in Table I. + tan $18\frac{1}{2}^\circ \times$ east component of whole wind variation as given in Table I., ... (4)

and the following variation obtained, which will hereafter be called the *meridional* diurnal variation of the wind, to distinguish it from the whole north and south movement given in Table I., and from that part of it which belongs to the land- and sea-breeze.

Table IV.—Meridional Diurnal Variation of the Velocity of the Wind at Bombay.

Bombay Civil Hours	0 to 1.	1–2.	2–3.	3–4.	4–5.	5–6.	6–7.	7–8.
Velocity in miles per hour	0·44 s.	0·23 s.	0·24 s.	0·09 n.	0·45 n.	0·64 n.	0·62 n.	0·47 n.
Bombay Civil Hours	8–9.	9–10.	10–11.	11–12.	12–13.	13–14.	14–15.	15–16.
Velocity in miles per hour	0·43 n.	0·03 s.	1·02 s.	1·53 s.	1·63 s.	1·70 s.	1·07 s.	0·40 s.
Bombay Civil Hours	16–17.	17–18.	18–19.	19–20.	20–21.	21–22.	22–23.	23–0.
Velocity in miles per hour	0·48 n.	0·97 n.	1·54 n.	1·61 n.	1·00 n.	0·36 n.	0·10 s.	0·37 s.

This variation is also graphically represented by fig. 8. Its value of course depends on the correctness of the assumption as to the nature of the land- and sea-breeze, which may be only approximately true, and the variation may therefore be subject to correction hereafter when the exact nature of the land- and sea-breeze becomes known.

7. It will be observed that the great distinguishing feature of the diurnal variation of the barometer, viz. the double period, is the most prominent one in the meridional

diurnal variation of the wind; and the same feature has been shown to be present in the longitudinal variation also; hence we naturally infer that the phenomena may be in some way interdependent, and are led to inquire after the nature of their relationship.

Confining our attention for the present to the meridional variation, it is difficult to conceive how any local peculiarity of geographical position could so modify the land- and sea-breeze (which we have seen follows chiefly, in its principal direction, the same law of progression as the temperature of the air) as to cause its law of progression in a north and south direction to be so widely different in character from that in the east and west direction as the variations in Table I. show it to be; and much more difficult to conceive how that modification (if it may be regarded as such) of the strictly local phenomenon which we know the land- and sea-breeze to be, should follow a law of progression similar to that of the diurnal variation of the barometer, which is perhaps the most universal and regular of all meteorological phenomena. It seems far more probable that the variation represented by fig. 8 is not a simple modification of the land- and sea-breeze by local peculiarities, but an indication of the existence of a double diurnal variation in the general movements of the atmosphere, as universal as, and moving synchronously with, the double diurnal variation of the barometer, but which has never before been noticed because of the unsuitable nature of all wind observations made before the invention of ROBINSON'S anemograph for exhibiting a variation of this kind; and it is not unreasonable to expect that similar variations will be found at other tropical stations by similarly reducing a sufficiently long series of suitable wind observations*. Now regarding that part of the diurnal variation of the wind at Bombay which is not directly attributable to the land- and sea-breeze as a universal phenomenon, perhaps its most surprising feature is that the hours about noon should occupy a position furthest removed to the *southward* of the mean direction-line A B, a feature which appears to be in direct opposition to the principles of HADLEY'S theory of the trade-winds, which is the theory that explains satisfactorily the land- and sea-breeze, and in which the wind is always supposed to blow towards the heated region, not *away from* it as shown by that feature of the variation; for, according to that theory, we should expect to find a decided tendency of the wind to blow from the north at that time in the northern hemisphere. And this feature is the more surprising when viewed side by side with the more extensive east and west movement, which is in perfect accordance with the theory.

Speaking about the sun's heating action on the atmosphere, and the effects resulting therefrom, Sir J. HERSCHEL has remarked, in his 'Meteorology,' art. 172:—"When anemometry is further perfected we may expect to trace the influence of this chain of causation into a morning and evening tendency of the wind (on a long average of observations) to draw *towards* the points of sunrise and sunset, to compensate the overflow from off the heated hemisphere which takes place aloft in a contrary direction."

---

* Observations of the direction of the wind are of no value for this purpose, unless combined with their corresponding observations of the velocity (not pressure) of the wind.

The expectation here expressed is certainly not realized by the diurnal wind-curve for Bombay; but it may not therefore be inferred that such a tendency does not exist, and may not eventually be traceable. The inference that may be drawn is that the same cause, working in an unexpected manner, produces other effects of an opposite nature which completely overwhelm the expected tendency, of whose existence, however, in a much smaller degree, there can be no doubt. But the principles of HADLEY'S theory fail also to explain the double reversal in the north and south direction which the wind undergoes daily; for, in accordance with them, the wind would be reversed in direction but once a day, just as in the case of the land- and sea-breeze, seeing that the temperature rises and falls but once a day. Turning to the longitudinal variation, which is approximately represented by fig. 7, the same difficulty is encountered in attempting to explain the double reversal of this curve by the same principles; and the directions of the wind indicated in the morning and afternoon hours are exactly the reverse of those expected by Sir J. HERSCHEL in the remark quoted above.

8. It seems highly improbable, then, that the meridional and longitudinal variations of the wind at Bombay are part of a system of convection-currents, such as would satisfy the requirements of HADLEY'S theory. The form of the curves seems rather to suggest the notion of a general bodily movement of the atmosphere (its lower strata as well as its upper) *outwards* in all directions from the middle of the hemisphere which is being heated *towards* the middle of that which is being cooled, succeeded by oscillatory movements consequent upon the disturbance of equilibrium thus caused. The notion of a general outflow of air (not an upper surface overflow merely) from the heated hemisphere has already been advanced by Sir JOHN HERSCHEL in his explanation of the diurnal variation of the barometer*; but he does not seem to have suspected that there would be more than one complete oscillation in the twenty-four hours, or that these movements of the air would be more marked than the convection-currents already referred to. After explaining that the heat of the sun produces on the air of one hemisphere a "considerable elevation of the lines of equal density [which when so elevated cease to be statical level lines], while the nightly chill on the other side acts in a contrary way on the opposite hemisphere," he says, "an indirect effect" on the barometer "results from the elevation of the surface of equilibrium on one side and depression below it on the other. To form some rough estimate of this effect, whose exact calculation would be difficult, we must consider that an elevation of 363 feet on one side [taking, *exempli gratiâ*, 20° Fahr. for the difference of day and night temperature] and a similar depression on the other, correspond to a slope of $3''\cdot5$ at the common boundary of the two hemispheres, down which the centre of gravity of each aërial column situate on that boundary (being unsupported laterally) tends to glide. The effect of this will be the production of *a general movement of air setting* OUTWARDS FROM *the heated hemisphere*, and which, though feeble (as its velocity would at its maximum hardly exceed a mile an hour), yet acting over the whole circumference of a great

---

* See HERSCHEL'S 'Meteorology,' art. 77 *a*.

circle of the globe, would transfer a sensible fraction of the whole atmosphere backwards and forwards."

Whether such a system of diurnal wind-currents as that which has been supposed, having a second complete oscillation during the night, is really a universal phenomenon, must be determined by extended observation and investigation in other localities; and whether the currents are originated and propagated in the manner that has been suggested, or whether they do not rather owe their origination in a more direct manner to the diurnal fluctuations of the temperature of the air*, it is perhaps premature to speculate; but in the mean time it appears to be worth while to compare the observations that are available, with the conclusions that may be drawn from the hypothesis of the existence of such currents, and to mark the relations that will be found to obtain between the diurnal variations of the wind and other meteorological phenomena.

9. If such a system of diurnal wind-currents really exists in nature, we should expect to find the ordinates of the two curves representing the meridional diurnal variations of the wind for the northern and southern hemispheres exactly reversed in direction, that they increase in range with the latitude in both hemispheres, and vanish at the equator. We should also expect to find that the range of the curve for each place of observation has a yearly variation corresponding to the sun's change of declination, being smallest when the sun's zenith distance is smallest and increasing as it increases, and *vice versâ.* Such a variation in range is clearly shown by the mean monthly curves for Bombay. They give the following diurnal ranges, which are the differences of the mean ordinates for $12\frac{1}{2}$ and $18\frac{1}{2}$ hours in each month, measured in the same manner as those given in Table IV.

TABLE V.—Ranges of the Meridional Diurnal Variation of the Wind and the Land- and Sea-breeze at Bombay, and the Ratios of the latter to the former.

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Range of meridional variation	6·1	6·1	3·6	3·2	1·7	0·8	0·2	1·6	2·3	4·5	5·9	5·2
Range of land- and sea-breeze.....................	14·8	16·1	17·5	16·2	11·9	8·5	2·8	4·1	8·5	14·3	16·9	14·9
Ratios..........................	2·3	2·6	4·9	5·0	7·0	10·6	14·0	2·6	3·7	3·2	2·1	2·9

These ranges furnish another argument in favour of the meridional diurnal variation of the wind having an origin independent of that of the land- and sea-breeze; for if both were a consequence of the same local influences, they would most probably vary in such a manner that the ratio of one to the other would be constant. The numbers in the third line of Table V. show the mean diurnal ranges of the land- and sea-breeze between 7½ and 15½ hours in each month of the year, the values for these hours having been obtained in the same manner as those given in Table II. They appear to show that the two variations are not the effects of the same persistent *local* influences.

---

* The fact that the curve (fig. 8) attains its maximum south position not long after noon (the time when any particular place is receiving heat most rapidly from the sun), and *before* (not after) the time of maximum temperature, which occurs about $14\frac{1}{2}$ hours, appears to point to a direct action of the heated air in expanding itself *outwards* as well as upwards; for if the south current were produced solely in the manner suggested by Sir JOHN HERSCHEL, we should expect it to attain its maximum strength *after* the time of maximum temperature, not before it. The same feature which has here been pointed out as appertaining to fig. 8 will hereafter be seen to exist in similar curves for other places (see figs. 12, 13, and 14).

10. Our attention has thus far been chiefly confined to that part of the diurnal variation of the wind which manifests itself in the direction of meridian lines; but the same considerations would lead us to expect an east and west diurnal variation also, of a somewhat similar character, showing that the wind blows away from, not towards, the sun, and therefore from the east during the morning hours, and from the west during the afternoon hours, and having similar oscillatory movements during the night. Reasons for believing that such a variation does really exist have been given in paragraph 5. Its times of maxima and minima will probably be about the same time at which the meridional variation is at its mean positions, and *vice versâ*; and its directions will, unlike the meridional variation, be the same at the same times at places in both hemispheres that are equidistant from the equator.

Unfortunately the observations for Bombay alone will not suffice for the exact determination of the nature of the mean longitudinal diurnal variation of the wind for the whole year, until the precise character of the land- and sea-breeze has been found by a comparison of the observations with similar ones made elsewhere; but, judging from what has preceded, we may assume as a first approximation to the truth, and for the sake of carrying the investigation a step further, that it is similar to the meridional variation, when the north components of the latter are taken to represent the west components of the former, but earlier in phase by about three hours.

Taking, then, the meridional variation as a type of the longitudinal variation, and combining the two, we have the epitrochoidal curve represented by fig. 9, which may be regarded as a typical curve representing the diurnal variation of the wind in low northern latitudes; and again combining the two after reversing the meridional variation, we get the curve represented by fig. 10, which may be regarded as a typical curve representing the diurnal variation of the wind in low southern latitudes.

The curves show a double diurnal right-handed rotation, in the same direction as the hands of a watch, for the northern hemisphere, and a double diurnal left-handed rotation, in the opposite direction to watch-hands, for the southern hemisphere.

11. In the curve (fig. 1) showing the mean diurnal variation of the wind at Bombay, the *double* diurnal rotation is converted into a single rotation by the influence of the land- and sea-breeze; but the tendency towards a double rotation is well marked, and the mean diurnal variation for the months July and August, when the effect of the land- and sea-breeze is very slight, clearly exhibits the double rotation. This variation is given in Table III., and represented graphically by fig. 11.

12. The following extracts from the discussion of the diurnal variations of meteorological phenomena for St. Helena, 1841 to 1843, by General Sir Edward Sabine, are almost an exact description of what would follow from the superposition of a diurnal variation like

that represented by the typical curve (fig. 10) upon the south-east trade-wind of that station, and they appear to put beyond doubt the existence of a double diurnal left-handed rotatory variation of the wind in southern low latitudes.

"From Table XLI. we learn that the wind is more easterly generally during the hours of the day than during the night, and that it is *most easterly about noon.* The direction varies little during the night, but there is a tendency to a *more southerly* direction about *daybreak*, and *just after sunset.* The force of the wind appears to have a *decided maximum* between 22^h and 23^h *, and a *minimum* about 4^h. From 5^h or 6^h to 15^h it remains nearly stationary, except that there is a tendency to a *second maximum* at 11^h shown in both years, *followed by a minimum* also of inferior character. At 13^h, at 0^h, and 16^h the pressure coincides with the mean of the twenty-four hours."

The variation in direction has also two maxima and two minima with regular progressions from one to another, and the turning-points occur at intervals of about six hours.

13. Having advanced reasons for believing that a regular diurnal variation in the movements of the atmosphere does really exist, and that it is probably universal, and having shown, to the extent to which the limited nature of the observations permit, the probable character of that variation, it may now be shown that the diurnal variation of the barometer is directly deducible from the wind variation. The best way of showing this will perhaps be to adopt the suggestions recently made by Dr. BALFOUR STEWART, and to suppose the existence of several "meteorological blockades." A figure will best illustrate what is intended (see Plate XXXIV. fig. 15).

Let W E represent the earth's equator, divided into hourly intervals, and let the horizontal lines above and below it represent parallels of north and south latitude respectively. The arrows will then indicate the directions towards which the wind is blowing at the times at which they are placed, in accordance with the typical curves fig. 9 and fig. 10. They are marked only for those times when the winds are at one or other of the four cardinal directions; but it is to be understood that there is a gradual progression from one to the other with the time, producing two right-handed rotations along the parallel of north latitude, and two opposite rotations along the parallel of south latitude; and that at the equator the wind gradually dies away to a calm, and is then succeeded by a wind in the opposite direction, which gradually increases to a maximum. Let meridian lines be drawn through those times when the meridional variation of the wind on the parallels of latitude passes through zero, which are about the times when the longitudinal variation attains its maxima east and west positions; these lines will divide the space between the parallels of latitude into four areas, *a*, *b*, *c*, and *d*, the boundaries of which may be taken to represent those of four separate blockades. An inspection of the figure will show that air is flowing out of the areas *a* and *c* in all directions, and flowing into the areas *b* and *d* from all directions. A barometer placed in the area *a* or *c* will therefore show a diminishing pressure, while one placed in the area *b* or *d* will show an increasing pressure.

---

* Astronomical reckoning.

Or we may suppose the figure to represent the winds of a system which revolves about the earth with the sun from east to west, and hence each place of observation between the two parallels of latitude will successively pass from west to east through the various conditions of the several areas. Take, for example, a station situated on the equator at the time 6 hours; air is then flowing towards it from all directions, and consequently at that time the barometer is rapidly rising; when the place has advanced to, say, 8 hours, air is still flowing towards it from the north and south, but with a less velocity than when it was at 6 hours; air is also flowing towards it from the east but leaving it on the west, though less rapidly, and the barometer is still rising, but less rapidly than at 6 hours; when the station has advanced to $9\frac{1}{2}$ hours air has ceased to blow towards it from the north and south, and it is importing just as much air from the east as it is exporting on the west; the barometer is now stationary and has reached a maximum. When the place arrives at 11 hours, the air has begun to flow outwards towards the north and south, and more air is leaving it on the west than is blowing towards it from the east, and in consequence the barometer has begun to fall. At about 13 hours air is leaving the place in all directions and the barometer is falling rapidly, and continues to fall until the station reaches 16 hours, when air has ceased to flow from it towards the north and south, and is leaving it on the east at the same rate at which air is being received from the west; the barometer has now reached its minimum position and is again stationary. As the station advances still further, air begins to blow towards it from the north and south, and to leave it less rapidly on the east than it receives air from the west, and the barometer begins to rise; about 19 hours, air is flowing towards the station from all directions and the barometer is rising rapidly, and it reaches a second maximum at about 22 hours, when the air has ceased to flow towards the station from the north and south and is blowing inwards on the east at the same rate at which it is blowing outwards on the west. From 22 hours to $9\frac{1}{2}$ hours the same cycle of changes as that which occurs from $9\frac{1}{2}$ hours to 22 hours is repeated, but on a less extensive scale. The same results will follow for a station situated north or south of the equator, if it be borne in mind that the north and south winds increase in strength with the distance of the place from the equator.

It will be observed that the movements of the barometer deduced from the figure are all in accordance with observation.

14. The curves fig. 9 and fig. 10 are also of some importance, as will presently appear, when viewed in connexion with the "law of gyration" propounded by Professor DOVE; for they will be seen to accord with some of the results of his investigations, viz. the marked tendency of the wind to rotate in a right-handed direction in the northern hemisphere, and in the opposite direction in the southern hemisphere.

15. The whole of the wind which blows at Bombay on any particular day may be regarded as made up of three distinct parts:—1st, that due to the double diurnal variation of the wind, and which is most persistent in its character; 2nd, the land- and sea-breeze, which is also very persistent in all except the monsoon months, June, July, August, and September; and 3rd, that wind which remains after the elimination of the

double diurnal variation and the land- and sea-breeze, and which may be called the daily normal wind (this wind is the most irregular in direction and variable in velocity). The mean resultant wind for the whole year is represented by the line C F, fig. 1*. When all three winds are blowing normally there will be no rotation of the vane, but only a diurnal oscillation right and left about the daily normal wind. This is the most usual condition of the vane. The range of the oscillations will be very small if the daily normal is very strong, and will increase as the normal diminishes in strength. But whenever the daily normal wind becomes so small or varies in direction so as to lie wholly within the diurnal-variation curve, a single right-handed revolution of the vane will occur on that day, but it will not be a uniform movement all round the compass. Suppose, for instance, that the daily normal is a north wind of velocity one mile per hour; and let the thick line C D in fig. 1 represent this normal, then lines drawn from the point D to any part of the diurnal-variation curve will show the direction of the vane at the times indicated along the course of the curve and to which the lines are drawn. It will be observed that the vane will alter its direction very gradually in the afternoon hours, and rather quickly between 21 and 0 hours; that it will be almost steady at east from 6 to 9 hours, after which a very rapid movement will take place, changing its direction 180° in about three hours. Such movements of the vane are of very frequent occurrence at Bombay during most of the year, but especially during the month of October, when the daily normal wind has a smaller velocity than at any other time of the year and is very variable in direction. Professor Dove pointed out the fact that right-handed rotations of the vane at Bombay were more numerous in October than in any other month of the year; and he suggested that the operation of local causes might account for the excess, but he left the point to the decision of the observer. The foregoing explanation of right-handed rotations of the vane throughout the year affords also an explanation of the greater number of rotations in October, and shows it to be due to the fact that the daily normal winds of that month are smaller and more variable than in any other month, and therefore lie more frequently *within* the diurnal-variation curve. A separate treatment of the daily normal winds, so as to show their variability at different times of the year, is now in progress, and it brings out the fact here mentioned very prominently. Further, whenever the land- and sea-breeze and also the daily normal are simultaneously almost entirely suspended (which, however, rarely occurs, and never except during the monsoon months), there will be a double rotation of the vane in one day, the movement round the compass approaching more and more nearly to uniformity of progression as the land- and sea-breeze and the daily normal become less and less.

It will be noticed that the daily normals which blow from different directions will all be differently modified by the superposition upon them of the diurnal variation of the wind:

---

* The almost exact coincidence of the direction of the resultant wind for the whole year with that of the sea-breeze is remarkable; and the fact seems to point to the same cause for the origination of one as for the other, viz. the higher temperature (on the average) of the air over the land compared with that of the air over the sea. Observations made on the eastern sea-board of India will show whether there is any truth in this conjecture.

suppose, for instance, that the daily normal is a north wind with a constant velocity throughout the day of ten miles per hour, and that a diurnal variation like that represented by fig. 1 is superimposed upon it, then at 21½ hours and 11 hours the vane will be unaltered, but the wind will be increased in velocity at 21½ hours, and diminished in velocity at 11 hours, whilst at 7½ hours the vane will be deflected furthest to the right, and at 15½ hours furthest to the left. A daily normal from the south will be oppositely affected both with regard to velocity and direction, supposing the observer to face the wind. Next, suppose that the daily normal is a wind from the west of constant velocity and of the same strength as before, then at 13 hours and 22 hours the vane will be unchanged, but the wind will have increased in velocity at the former time and diminished at the latter; whilst at 18½ hours the vane will be deflected furthest to the right, and at 7½ hours furthest to the left. An east normal wind will be oppositely affected both as regards direction and velocity. Similarly, for daily normals from other directions, there will be hours (different for each different normal) when the vane will be unaffected by the superposition of the diurnal variation, but when the wind will be modified in velocity, and other regularly recurring times of the day when each different normal will be deflected to its extreme right and left positions; but these times will not be the same for any two different normals. Hence arise many apparently fortuitous movements of the vane, which, however, may be reduced to order by the foregoing method of separation.

16. Having now acquired a knowledge of the nature of the diurnal variation of the wind at Bombay, and the influence which it exerts on the movements of the vane, it is evident from an examination of the anemograms that by far the greater part of the right-handed rotation of the vane at Bombay is due to the *diurnal variation* of the wind rather than to a veering round of the daily normal wind; and it will be needful to make a special investigation of the wind records at Bombay, eliminating the effects of the diurnal variation, before it can be said that they show an excess of "direct" over "retrograde" rotation due to the cause assigned by Professor DOVE in his 'Law of Storms.'

17. The anemograms of the seven British observatories, published in the 'Quarterly Weather Reports of the Meteorological Office,' show numerous instances in the summer months of *diurnal* right-handed rotations of the vane similar to those which occur at Bombay, and very many cases of like diurnal modifications of a daily normal from the same direction. As instances of the former kind, may be mentioned the anemograms for Falmouth for the 30th June, 1st and 2nd July, 1869; and of the latter kind those for Stonyhurst for the 30th June and 1st July, 1869. Such instances appear to show that a systematic *diurnal* variation of the wind obtained in the British Isles; and for the sake of testing this point, an experimental reduction of fifty of the Falmouth anemograms for days between the 1st April and 2nd September, 1869, has been made. Those days on which the velocity exceeded 15 miles per hour for the whole day, or a large portion of it, were rejected as disturbed days. The tabulations and reductions were made exactly in the same manner as the Bombay observations are tabulated and reduced, so that the results are strictly comparable with those for Bombay. The results are contained in the following Table, and also graphically represented by fig. 12.

TABLE VI.—Mean North or South and East or West components of the Wind at Falmouth for fifty days between the 1st April and 2nd September, 1869, for each hour of the day, also their mean diurnal variations for the same period.

Falmouth Civil Hours......	0 to 1.	1–2.	2–3.	3–4.	4–5.	5–6.	6–7.	7–8.
N. or S. component	2·9 N.	3·5 N.	3·8 N.	3·5 N.	4·1 N.	3·5 N.	3·1 N.	5·8 N.
Variation	2·6 N.	3·2 N.	3·5 N.	3·2 N.	3·8 N.	3·2 N.	2·8 N.	2·5 N.
E. or W. component	2·0 W.	1·9 W.	1·7 W.	1·3 W.	1·4 W.	0·5 W.	0·8 W.	1·2 E.
Variation	1·8 W.	1·7 W.	1·5 W.	1·1 W.	1·2 W.	0·3 W.	0·6 W.	1·4 E.
Falmouth Civil Hours......	8–9.	9–10.	10–11.	11–12.	12–13.	13–14.	14–15.	15–16.
N. or S. component	1·8 N.	0·2 S.	2·1 S.	3·3 S.	4·4 S.	4·4 S.	3·9 S.	2·8 S.
Variation	1·5 N.	0·5 S.	2·4 S.	3·6 S.	4·7 S.	4·7 S.	4·2 S.	3·1 S.
E. or W. component	2·2 E.	3·1 E.	4·0 E.	2·8 E.	1·6 E.	1·2 E.	0·2 W.	0·0
Variation	2·4 E.	3·3 E.	4·2 E.	3·0 E.	1·8 E.	1·4 E.	0·0	0·2 E.
Falmouth Civil Hours......	16–17.	17–18.	18–19.	19–20.	20–21.	1–22.	22–23.	23–0.
N. or S. component	2·2 S.	0·8 S.	0·3 N.	1·9 N.	2·2 N.	1·7 N.	2·2 N.	2·5 N.
Variation	2·5 S.	1·1 S.	0·0	1·6 N.	1·9 N.	1·4 N.	1·9 N.	2·2 N.
E. or W. component	1·2 W.	2·0 W.	1·8 W.	2·0 W.	1·6 W.	2·2 W.	2·1 W.	2·0 W.
Variation	1·0 W.	1·8 W.	1·6 W.	1·8 W.	1·4 W.	2·0 W.	1·9 W.	1·8 W.

The mean components for the whole period are 0·3 N. and 0·2 W.

Considering the small number of observations from which it is deduced, the curve is a remarkably regular one, and accords in many respects with the typical curve, fig. 9. The rotation is right-handed; the morning hours occupy the east side of the curve, the hours about midday are to the south, and the afternoon hours to the west, while the midnight hours are crowded together towards the north-west, but there are no definite indications of a double diurnal rotation. This figure will probably interest many magneticians; for when it is turned in a right-handed direction through an angle of *about* 90° in the plane of the paper, it bears a very striking resemblance to a curve which represents the mean diurnal variation of the earth's magnetic force in a horizontal plane at Greenwich; and which is published in the Greenwich Observations for 1867.

18. The Toronto observations of the wind also show a diurnal variation which rotates in a right-handed direction. The following results (see Table VII., p. 16) are deduced from the "Meteorological Abstracts, Toronto 1854–1859," Tables LII. and LIII.

Fig. 13 is a graphic representation of this variation, from which it will be seen that the diurnal variation of the wind at Toronto has similar features to those of the Falmouth curve, and that it resembles the typical curve (fig. 9) in the same particulars. There is an absence of any distinct indication of a *double* diurnal rotation in this case also.

TABLE VII.—Mean North or South and East or West components of the Wind at Toronto for each hour of the day, during the years 1854 to 1859 inclusive, also their mean diurnal variations for the same period.

Toronto Civil Hours	0 to 1.	1–2.	2–3.	3–4.	4–5.	5–6.	6–7.	7–8.
N. or S. component	1·65 N.	1·78 N.	1·78 N.	1·75 N.	1·67 N.	1·66 N.	1·71 N.	1·65 N.
Variation	0·64 N.	0·77 N.	0·77 N.	0·74 N.	0·66 N.	0·65 N.	0·70 N.	0·64 N.
E. or W. component	1·53 W.	1·49 W.	1·50 W.	1·42 W.	1·35 W.	1·30 W.	1·43 W.	1·49 W.
Variation	0·40 E.	0·44 E.	0·43 E.	0·51 E.	0·58 E.	0·63 E.	0·50 E.	0·44 E.

Toronto Civil Hours	8–9.	9–10.	10–11.	11–12.	12–13.	13–14.	14–15.	15–16.
N. or S. component	1·49 N.	1·02 N.	0·38 N.	0·25 S.	0·59 S.	0·61 S.	0·52 S.	0·00
Variation	0·48 N.	0·01 N.	0·63 S.	1·26 S.	1·60 S.	1·62 S.	1·53 S.	1·07 S.
E. or W. component	1·65 W.	2·00 W.	2·15 W.	2·36 W.	2·54 W.	2·64 W.	2·65 W.	2·56 W.
Variation	0·28 E.	0·07 W.	0·22 W.	0·43 W.	0·61 W.	0·71 W.	0·72 W.	0·63 W.

Toronto Civil Hours	16–17.	17–18.	18–19.	19–20.	20–21.	21–22.	22–23.	23–0.
N. or S. component	0·58 N.	0·85 N.	1·07 N.	1·23 N.	1·31 N.	1·50 N.	1·58 N.	1·58 N.
Variation	0·43 S.	0·16 S.	0·06 N.	0·22 N.	0·30 N.	0·49 N.	0·57 N.	0·57 N.
E. or W. component	2·53 W.	2·33 W.	2·17 W.	2·04 W.	1·95 W.	1·85 W.	1·75 W.	1·64 W.
Variation	0·60 W.	0·40 W.	0·24 W.	0·11 W.	0·02 W.	0·08 E.	0·18 E.	0·29 E.

The mean components for the whole period are 1·01 N. and 1·93 W.

19. Now, confining our attention to the northern hemisphere, and supposing the sun to have no declination, a little consideration will show that a *double* diurnal variation of the wind like that represented by fig. 9 cannot subsist in all latitudes, for such a supposition would lead to a contradiction when the pole was reached; for it would require that winds should be found there blowing in opposite directions at the same time, which is of course absurd. The two influences, however, which produce the two north and south oscillations in low latitudes may be supposed to exist at the same time even at the pole, tending to produce motion in opposite directions: the movement produced will therefore be due to the difference of these influences; and as the greater influence is that which produces the larger oscillation in low latitudes, the result will be a transference of air across the pole from the hot to the cold hemisphere, or, which is the same thing, a motion of the air *from the sun.* It follows that the diurnal variation at the pole will consist of a single rotation, the diurnal-variation curve being a circle—or, in other words, a vane placed there and influenced only by this variation will "veer" round at the uniform rate of 15° per hour. If we suppose such a variation to exist at the pole, then in middle latitudes we should expect to find the diurnal variation of the wind partaking of the characteristics both of the variation at the pole and that in low latitudes; and such

appears to be the case with the variations given for Toronto and Falmouth: the double rotation is converted into a single one in both instances; but the rate of rotation is decidedly *not uniform*, being much slower during the night than during the day, although the rate during the day is much slower than in low latitudes. Referring to the typical curve fig. 9, we see that during the day it rotates through 180° in a little over 6 hours; and from the remarks for St. Helena, it may be inferred that there the diurnal wind-curve rotates through the same distance in about the same time, whilst at Falmouth and Toronto the curve rotates during the daytime through 180° in about 9 hours. At the pole, the curve, as we have supposed it, rotates through 180° in 12 hours.

20. The results deduced from the curves that have been discussed afford a possible, if not a probable, explanation of the observed excess of "direct" rotation of the wind-vane over "retrograde" rotation in the northern hemisphere, and of the opposite excess in the southern hemisphere; and it is one that follows directly from the observed movements of the wind. They have therefore some relevance in the discussion of storms; for it should be shown that there still remains an excess of direct over retrograde rotation, after eliminating the effects of the diurnal variation of the wind, before any allowances are made for "veering" of the wind in deducing probabilities of the weather from observations made at the *same hours* of successive days; whilst they show the small magnitude of allowances that should be made for "*veering*" or "*backing*," as the case may be, in connecting observations that are made at *different hours* of the day; and by reducing the number of the movements of the vane for which reasons have still to be sought, and which would otherwise be misleading, they will increase to some extent the value of weather probabilities. Some of the foregoing remarks have been made because the writer has observed that, in an "inquiry into the connexion between strong winds and barometric differences" by the Director of the London Meteorological Office, an allowance of 45° per day has been made for the "veering" of a *strong* wind, in deducing the probable wind that would follow a certain barometric difference between two stations, in accordance with Buys Ballot's law. The subject appears to be worthy of further elucidation, prior to the adoption of daily allowances for "*veering*" in future tentative investigations of a similar nature.

21. In conclusion the writer would say that he makes no pretensions to having framed a *complete* explanation of the diurnal variations of the barometer. In their present stage, he regards the notions he has advanced more as providing a working hypothesis than as a final solution of the long-vexed question of the barometric tides. As a suggestion, it supplies in some measure a want that has long been felt, in that it points out a definite line of inquiry which cannot fail, if followed, to be productive of most valuable results. The fact that the hypothesis undesignedly forms a connexion between two meteorological phenomena (viz. the diurnal variation of the barometer and that movement of the air which Dove has called the "Law of Gyration") which have hitherto been regarded as perfectly independent of each other, and that it simultaneously explains both, appears to be in its favour; and it may be that it contains a germ of truth which, when fully developed, will form no small addition to the foundations of meteorological science.

POSTSCRIPT.

Since the completion of the above discussion, the Quarterly Weather Report of the Meteorological Office for the first quarter of 1871, containing the Anemometrical Results for Sandwick Manse, Orkney, 1863–68, has been received at Bombay. From Table II. page [36] the mean north and east components for each hour of the day in the whole period have been extracted. They are as follows:—

Mean North and East components of the Wind at Sandwick Manse, Orkney, for each hour of the day from 1863 to 1868, also their mean diurnal variations for the same period.

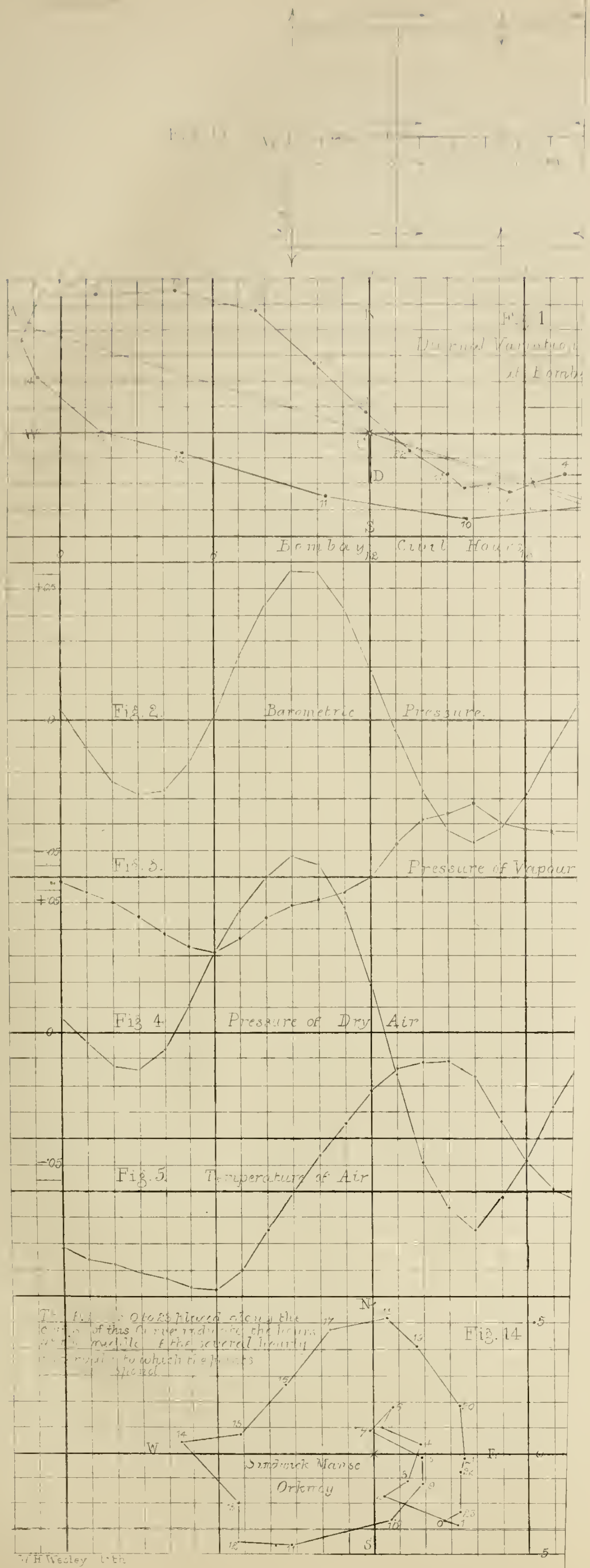
Sandwick Manse Civil Hours	0.	1.	2.	3.	4.	5.	6.	7.
N. component	−2·65	−2·67	−2·55	−2·49	−2·34	−2·28	−2·20	−2·29
Variation	−0·27	−0·29	−0·17	−0·11	+0·04	+0·10	+0·18	+0·09
E. component	−2·90	−2·85	−3·13	−3·04	−2·99	−3·14	−3·09	−3·18
Variation	+0·27	+0·32	+0·04	+0·13	+0·18	+0·03	+0·08	−0·01

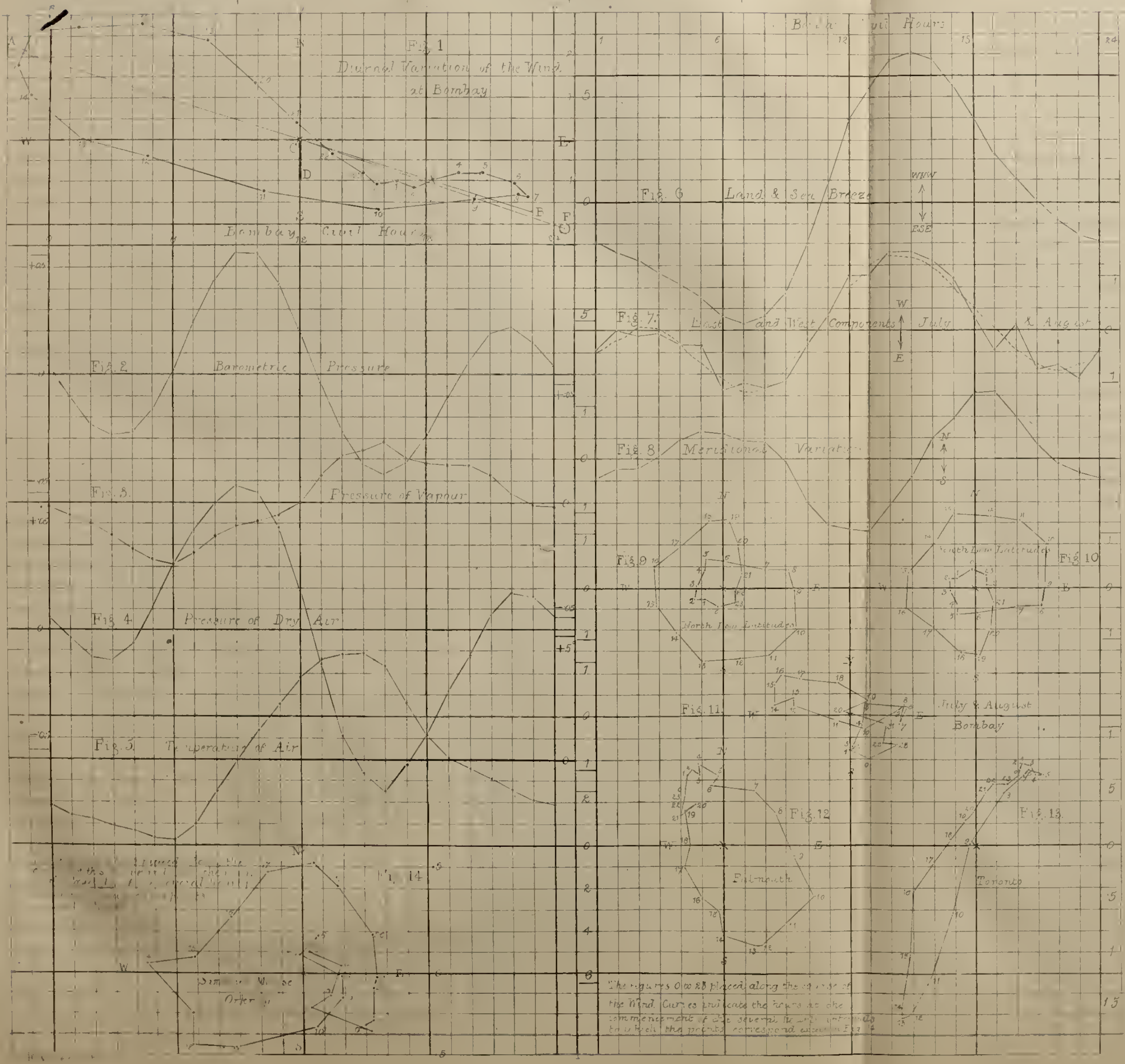
Sandwick Manse Civil Hours	8.	9.	10.	11.	12.	13.	14.	15.
N. component	−2·39	−2·50	−2·65	−2·74	−2·73	−2·58	−2·33	−2·30
Variation	−0·01	−0·12	−0·27	−0·36	−0·35	−0·20	+0·05	+0·08
E. component	−2·98	−2·98	−3·10	−3·49	−3·70	−3·69	−3·92	−3·68
Variation	+0·19	+0·19	+0·07	−0·32	−0·53	−0·52	−0·75	−0·51

Sandwick Manse Civil Hours	16.	17.	18.	19.	20.	21.	22.	23.
N. component	−2·11	−1·90	−1·86	−1·97	−2·19	−2·40	−2·45	−2·62
Variation	+0·27	+0·48	+0·52	+0·41	+0·19	−0·02	−0·07	−0·24
E. component	−3·51	−3·34	−3·11	−3·00	−2·84	−2·82	−2·84	−2·84
Variation	−0·34	−0·17	+0·06	+0·17	+0·33	+0·35	+0·33	+0·33

The mean components for the whole period are N. −2·38 and E. −3·17.

The variation of the north components shows a decided *double* period having maxima about 6 and 18 hours and minima about 0 and 12 hours, like the meridional variation of the wind at Bombay. The variation of the east components is less regular, but the double period, though not strongly marked, is nevertheless unmistakable in this variation also. It has a minimum about 14 hours and a maximum about 21 hours, a second minimum during the early morning hours and a second maximum between 8 and 9 hours, showing it to be of like character to the longitudinal variation of the wind at Bombay. The combination of these two variations produces a curve (fig. 14) which possesses the same general features as the typical curve fig. 9.





The figures 0 to 23 placed along the course of the Wind Curves indicate the hours at the commencement of the several hourly intervals to which the points correspond except in Fig. 14

I*. *On the Osteology of the* Hyopotamidæ. *By Dr.* W. KOWALEVSKY.

Communicated by Professor HUXLEY, *Sec. R.S.*

Received December 19, 1872,—Read February 6, 1873.

Introduction.

THE paper which I lay before the Society is an attempt to treat with sufficient osteological detail an extinct family of Ungulates which had an immense range of distribution and a great variety of forms in the two periods of the earth's history which preceded our own. The fate this family has met with at the hands of palæontologists is a somewhat sad one, presenting a warning example of the unscientific method that was paramount in the palæontology of the Mammalia after the time of CUVIER. With the exception of England, where the study of fossil Mammalia was founded on a sound basis, and some glorious exceptions on the continent, we have very few good palæontological memoirs in which the osteology of extinct mammals has been treated with sufficient detail and discrimination; and things have come to such a pass, that we know far better the osteology of South American, Australian, and Asiatic genera of fossil mammals than of those found in Europe. Nearly all fossil Mammalia which have been described in detail belong to genera that still exist on our globe, or whose differences from fossil forms are trifling. After the splendid osteological investigations of CUVIER had revealed to science a glimpse of a new mammalian world of wonderful richness, his successors have been bent rather on multiplying the diversity of this extinct creation, than on diligently studying the organization of the fossil forms that successively turned up under the zeal of amateurs and collectors.

From the year 1828, and even before, when LAIZER, POMEL, CROISET, and others began to give short notices on the Mammalia of Auvergne, mammalian genera and species from this locality have been multiplied at a prodigious rate, every private collector giving his own generic and specific names, with no better description than stating the real or supposed number of teeth, and some phrases as to the general resemblances of the fossil in question. Others substituted in their short notices other names, while the scientific work of description did not proceed further than the mere counting of the number of teeth. This process has given rise to such an utter confusion in the palæontology of the extinct Paridigitata, that even now (forty years after the date of the earliest notices) we are utterly ignorant of the true extent and organization of the Miocene mammalian fauna of Auvergne, for instance—though materials for a detailed study of the subject abound in all great public, and many private, collections, the fossils being very common. No palæontologist, even of the highest standing, could boast of knowing, in our own time, what *Dremotherium*, *Dorcatherium*, *Elaphotherium*, *Gelocus*, and so on really are, what are the bones belonging to each set of teeth (as the names were mostly given to these last), whether they had horns or were hornless like the *Tragulidæ*, and so on. If we add that German authors described the genera of Paridigitates which were found and named in France under different names (as *Palæomeryx*, *Microtherium*, *Hyotherium*, and so on), when they came from German localities, the confusion may be guessed. Having no good descriptions and no figures of the genera noticed in France, the German authors almost necessarily fell into the mistake of renaming what was already named. Once named, the genus was allowed to go forth with the short and wholly insufficient characteristics given to it by the first describer, the impossibility of adding one's name after the generic or specific designation seeming to take all interest from it. And this, moreover, is the best case; for frequently the same form was described by another palæontologist under a different generic name, or, if this was utterly impossible, a new species was made of it, founded on some difference in size or other trifling character. Happily, however, a reaction began to set in, one of the first to head it on the Continent being RÜTIMEYER, who did not confine his study merely to the teeth of fossil Mammalia, but aimed with brilliant success at a complete investigation of the osteology of the extinct genera and of their affinities with the living ones. GAUDRY'S work on the fossils of Pikermi (the best palæontological work that has appeared in France since CUVIER'S 'Ossemens Fossiles'), FRAAS'S 'Fauna von Steinheim,' ALPHONSE MILNE-EDWARDS'S 'Oiseaux Fossiles,' and many others may be cited as examples to prove that the new tendency has fairly set in and will bear good fruit. The wide acceptance by thinking naturalists of DARWIN'S theory has given a new life to palæontological research; the investigation of fossil forms has been elevated from a merely inquisitive study of what were deemed to be arbitrary acts of creation to a deep scientific investigation of forms allied naturally and in direct connexion with those now peopling the globe, and the knowledge of which will remain imperfect and incomplete without a thorough knowledge of all the forms that have preceded them in the past history of our globe.

The foregoing observations are intended only as a sort of apology for the somewhat minute osteological details into which it seemed to me necessary to enter in my description of the two genera which form the subject of the present memoir; before, however, we proceed to the concrete description of their skeleton, it is necessary to offer a few remarks on the position they hold among other fossil Paridigitata, as it seems to me that it has not been duly recognized by any previous author.

In all our speculations about the history and origin of the Paridigitata, a paramount importance has always been ascribed to *Anoplotherium*, as the most ancient form of the Paridigitate series. Now, seeing the reduced state of the skeleton of *Anoplotherium*, there cannot be the slightest doubt that this position is an entirely usurped one. How this state of things originated is easily accounted for. *Anoplotherium* had the good fortune to be found and described by CUVIER, who gave a thoroughly good description of its osteology, and, comparing it with some of the living Paridigitates, found that it and they possess many features in common. The naturalists who have ventured to theorize during the period of purely descriptive science which lies between the time of CUVIER and the complete revolution caused by DARWIN'S great work, looked always at the accurate and talented description of CUVIER, finding no good materials in the works of modern palæontologists from which to draw their means of generalization. As this absence of detailed descriptions of fossil European Mammalia was prolonged till our own time, we can understand how, even after the great revolution caused by the publication of DARWIN'S views, all writers that were leading the new movement of evolution, and trying to apply the theory of descent to our modern Paridigitata, had still to consult the works of CUVIER to find full and accurate information. There they could find only *Anoplotherium* fully described (as the *Xiphodon* and, especially, *Dichobune* were very much neglected in the 'Ossemens Fossiles'); and as it was, moreover, the most ancient form known, they placed it at the commencement of their pedigrees of Paridigitata. But if we consider the structure of the feet in *Anoplotherium*, we cannot avoid the conclusion that this genus is only an exceedingly reduced form, descended from some earlier Ungulate of the early Tertiary or, more probably, Cretaceous period. *Anoplotherium* is clearly the last remnant of a dying-out branch, in no case the progenitor of the wonderfully rich and diversified Paridigitata which succeeded it in the Miocene period, and which became so enormously developed in the Upper Miocene and Pliocene epochs, forming in our own time perhaps one of the most richly developed of animal groups. The feet of *Anoplotherium* are so much reduced, presenting only two developed metacarpals and metatarsals, with merely rudiments of the lateral toes, which certainly existed in its ancestors, that we cannot imagine such a reduced form giving rise to Miocene or even modern Paridigitata, many of which have four completely developed metacarpals and metatarsals. Besides, it is a very general truth that only those families which were exuberantly developed in bygone times, presenting many subgenera and a great variety of specific forms of different size, have had any chance of leaving a progeny behind them. We see examples of this in some of our recent genera the pedigree of which is now very completely known. There can be, in my opinion, no reasonable doubt that the Horse descended from the *Palæotherium* (very probably the Rhinoceros had the same origin from a Palæotheroid form, though this is not so certain); and see what immense diversity we find in the *Palæotheridæ* of the Eocene and Miocene epochs. The quantity of described species of *Palæotherium* is only a small fraction of the quantity that really existed, as every one who looks through a large collection of Eocene teeth becomes aware. Besides, the *Palæotheridæ* range in size from *P. minimum* (known only by its metapodium), not larger than a rabbit, through all intermediate sizes to *P. magnum*, fully as large as our Rhinoceros. We may mention that the *Paloplotherium* and *Anchilophus* belonged also to this group, and are extensively developed in the Eocene epoch. Only such prolific types, sending branches in all directions, have any chance of not wholly dying out in the course of time. If, in the struggle for existence, through geological changes of climate, slow submergence of continents, and elevation of the former sea-bottom to the height of the Himalayas, many genera must have been destroyed, still some one branch may have remained, and by gradual modification through natural selection, and perhaps by the agency of some other unknown cause, has given rise to new genera and species better fitted for the changed circumstances of life.

We see the same truth illustrated in the case of the Tapir, which is the last representative of a group extensively developed in the Eocene epoch, as all those genera known under the names of *Pachynolophus*, *Lophiodon*, *Hyracotherium*, *Pliolophus* belonged clearly to the family of *Tapirinæ*.

On the contrary, *Anoplotherium* is exceedingly poor in specific forms, only two being known with certainty, without any great difference of size; and though future discoveries may possibly increase the number of species, it is doubtful if ever they were as numerous as those of other genera which peopled the earth at the same period. In my opinion, as I shall try to prove further on, the *Anoplotherium* is an aberrant and very reduced branch of the early Eocene Paridigitata, which has no direct connexion with the living ones, and the true line of descent of our Ruminantia must be traced through other genera of the early Eocene epoch.

If, on the other hand, we turn our attention to the *Hyopotamidæ*, it must be confessed that the richness of this family in subgeneric and specific forms ranging through all sizes is really astonishing; and we shall be hardly guilty of exaggeration in saying that the diversity of *Hyopotamidæ* in the Eocene and Miocene times was as great as the wonderful diversity of the Ruminantia is at the present day. That this is not fully acknowledged by palæontologists is due to the neglect with which this family has been treated, and which I shall endeavour to repair.

Under the name of *Hyopotamidæ* I understand all the Eocene and Miocene Paridigitata which had crescentic teeth, with five well-developed lobes on their upper molars. The family might be termed *Anthracotheridæ*, as the *Anthracotheria* are among the most prominent representatives of this group; but the *Hyopotamidæ* being richer in subgeneric forms, the family may perhaps better bear their name.

The chief character on which the genus *Hyopotamus* (under the different names of *Ancodus*, *Cyclognathus*, *Bothriodon*) was founded is the shape of the upper molars, of greater breadth than length, and having five well-developed crescents or lobes. No author has mentioned any bones belonging to different sets of teeth, on the real or supposed differences of which many species were founded. The priority of mentioning these teeth under the name of *Ancodus* is claimed by Pomel in his ‘Catalogue;’ but as he neither gave a good description of them, nor illustrated his short notices by figures, no palæontologist has accepted this name, and it may be considered extinct. In fact, long before Pomel, Cuvier, having received a jaw of this genus from Puy, compared it with *Chœropotamus* and *Anthracotherium*; and as he had only the back molars, he deemed it unnecessary to separate the new animal from *Anthracotherium*, and designated it under the name of *Anthracotherium velaunum.* In the year 1847, however, Professor OWEN, having received from the Marchioness of HASTINGS very good materials, as far as the dentition was concerned, studied with great accuracy the structure of these teeth, and found in them sufficient characteristic differences to justify their separation from *Anthracotherium* under the name of *Hyopotamus.* Notwithstanding that one of the characters on which the distinction was based (the complexity of the upper premolars) was found to be a mistake, these complex teeth being milk-molars and not premolars of the permanent dentition (see Quart. Journ. Geol. Soc. vol. iv. 1848, pl. vii. fig. 6; p^4 and p^3 are in reality d^4 and d^3), still there were other characters which entirely justified the distinction, as I shall show when we arrive at the description of the teeth. Professor OWEN gave such a thoroughly good and accurate description of these teeth, accompanied with plates, that he may be considered the founder of the genus. One year later, M. AYMARD, of Puy, in a footnote to his paper on *Entelodon*, mentioned the *Hyopotamidæ* from Ronzon (Puy) under the name of *Bothriodon*, as he believed them different from those described by Professor OWEN from Hempstead. But having compared an extensive series of jaws and parts of skulls from both localities, I have been unable to detect any difference in them, and therefore the fossils from Puy must be included under the same generic name as those from Hempstead. The only author who has accepted the genus *Bothriodon* of AYMARD is Professor GERVAIS, who, in his 'Paléontologie Française,' p. 192, says that the *Hyopotamus* is to be distinguished from *Bothriodon*; but I have not been able to find any reasons adduced in the descriptions of the two genera why Professor GERVAIS considers them distinct, or on what characters he has founded his distinction. Notwithstanding the care with which I instituted my comparison, I could not detect any differences between the *Hyopotamidæ* from Puy and those from Hempstead; and, so far as I can see, their separation into two distinct genera is entirely unfounded. Professor GERVAIS has described many portions of jaws from different localities in France, and has given them different specific names, the distinction being founded on size and on the fact of their having been found in different localities. As I reserve the discussion of specific differences for the end of my paper, I will not enter into the criticism of these doubtful species just now.

In the year 1861, Professor RÜTIMEYER figured and described, with great accuracy, some few upper molars of a small Hyopotamoid animal from Egerkingen. These teeth had, however, been previously referred by H. v. MEYER to a new genus, *Tapinodon.* Professor RÜTIMEYER had only true molar teeth from Egerkingen, and as they really did not present any fundamental difference from the *Hyopotami* of Professor OWEN, he considered them to belong to the same genus. The Egerkingen specimens being very small, RÜTIMEYER separated them specifically under the name of *Hyopotamus Gresslyi.* This discovery was very important, as it carried the genus into undoubted and even early Eocene strata*. Then came the discovery of the wonderfully rich Eocene fauna of

---

* I have no doubt that the small Eocene *Hyopotamidæ* will one day be generically separated from the true *Hyopotami*, as known from Puy and Hempstead, as their premolars are somewhat different. I shall not do

Mauremont, described in two memoirs by Pictet, De la Harpe, and Humbert. Here the *Hyopotamidæ* were much more numerous than at Egerkingen, and presented a great variety of size. Among these remains were some specimens identical with those found at Egerkingen, and they were correctly referred to the *Hyopotamus Gresslyi.* The largest species was said to be identical with *Hyopotamus crispus*, Gerv.; but as Professor Gervais, in the second edition of his 'Paléontologie Française,' referred the *Hyopotamus crispus* to *Xiphodon* (without any suitable ground, as it seems to me), the whole matter must be revised once more. I cannot refrain from stating here that, in their second memoir, Messrs. Pictet and Humbert have mixed jaws belonging to different animals in a very strange manner. For instance, the upper jaw figured (*l. c.* plate xxiv. fig. 3, *c*) as *Rhagatherium* is in reality a *Hyopotamus*, and the lower jaw (fig. 2) bears not the least resemblance to the true *Rhagatherium* mandible figured in the first memoir, and, in my opinion, belongs to *Hyracotherium* or *Anchilophus.* In the same paper, moreover, the two authors have figured and described a very interesting small Paridigitate mammal, which they called *Cainotherium Renevieri*; but there is not the slightest doubt that this small Ungulate cannot be referred to the genus *Cainotherium.* I have stated before that the chief characteristic distinction of the molars of *Hyopotamus*, as described by Professor Owen, consists in having five distinctly developed lobes or crescents to their upper molars. These five lobes or crescents are disposed transversely, three on the anterior half and two on the posterior half of each upper molar, as may be distinctly seen in Plate XXXIX. fig. 1. With the exception of *Dichodon* and *Merycopotamus*, all Eocene and Miocene Paridigitata with crescentic teeth had always five lobes on their upper molars, disposed in the same way as in *Hyopotamus*; and, so far as we know at present, the position of the five cusps of the upper molars is reversed only in two very characteristic genera, two being placed in front and three behind. These two genera are *Dichobune* and *Cainotherium*, which also by their osteological characters seem to stand in a very near and direct relation. Every mammalogist is aware how constant are the dental characters in large groups of Mammalia; and if I state that such different genera as *Camelopardalis*, *Camelus*, *Cervus*, and *Bos* show less amount of difference in the structure of their upper molars from one another* than exists between the molars of *Cainotherium Renevieri* and the *Cainotheria* from Auvergne, every one will readily admit that the so-called *Cainotherium Renevieri*, in which the five cusps of the upper molars are disposed in the same way as in all Hyopotamoids (three in front and two behind), cannot be put into the same genus with the true *Cainotheria*, in which the disposition of the cusps is reversed—two in front and three behind. (Messrs. Pictet and Humbert noticed this difference in their description, but they did not consider it important enough for a generic distinction.) The upper premolars show also some

---

this in the present paper, as I hope to collect more ample materials, not only for the dentition, but also the skeleton of the Eocene *Hyopotamidæ*.

* Professor Owen in Quart. Journ. Geol. Soc. vol. iv. p. 111.

differences from the true *Cainotheria*, and the lower molars even more. If we consider each lower molar as composed of four parts, two crescents on the outer side and two pillars closing the crescents on the inner side (Plate XXXIX. figs. 8–12, *ac*, *pc*, *ap*, *pp*), then we may state that, in the true *Cainotheria* from Auvergne, the back part of each posterior inner pillar is a little prolonged backwards into a small additional cusp; this prolongation is especially marked on the inner side of the last inferior molar, making the posterior additional talon of this tooth quite double. This difference may be clearly seen in comparing a lower jaw of a *Cainotherium* from Auvergne with the enlarged figures of Pictet ('Faune sidérolitique,' plate xxvi. fig. 9, *c*). By all these characters the *Cainotherium Renevieri*, Pict., differs from the true *Cainotheria*, and agrees entirely with the Eocene *Hyopotamidæ* figured by Rütimeyer and by Pictet himself. Therefore the *Cainotherium Renevieri* cannot remain in the genus in which it was put by Pictet, but must be arranged with the rest of the Eocene *Hyopotamidæ*, as *Hyopotamus Renevieri**.

I cannot refrain from stating that, in my opinion, the five-lobed character of the upper molars is of a too general value to be used for generic distinction. In fact all the Eocene and Miocene Paridigitate genera (with crescentic teeth) have five-lobed upper molars†, and therefore this character is as unfit for generic distinction, in this large assemblage of animals, as the fact of having four-lobed molars would be found unfit if we tried to apply it to the living Ruminantia; it is of too general a nature, all living Ruminantia having four-lobed upper molars.

In such cases where the true molars present too great a uniformity for furnishing good distinctive characters, the shape of the premolars may be of great use, as was well shown by Professors Rütimeyer and Hensel, in reference to Suina and Ruminantia. And, in fact, if we compare the premolars of the Eocene *Hyopotamidæ* figured by Pictet and Humbert, *Hyopotamus Gresslyi*, *H. Renevieri*, and even his *H. crispus* (*l. c.* plate xxiv. fig. 11), we shall see that all these Eocene *Hyopotamidæ*, though of such different size, agree together in the shape of their premolars, while they differ by the same character from the true Miocene *Hyopotamidæ* from Hempstead and Puy. As I hope soon to collect materials for a description not only of the dentition but even of the skeleton of these Eocene species, I will not enter further into this matter here, and I will only state that, by comparing the figures of Pictet with my plates, the reader will perceive that the premolars of all the Eocene *Hyopotamidæ* are, so to say, more ruminant-like: this is especially the case with premolars p^2 and p^3; they are considerably more elongated and not so high as in the *Hyopotamus* and *Anthracotherium*. Besides, I suspect from some bones seen in the collection in Lausanne, and especially from a metatarsal of *Hyopotamus* (*Cainotherium*) *Renevieri* figured by Pictet (*l. c.* plate xxvii. fig. 2), that some, if not all, of the Eocene *Hyopotamidæ* were didactyle, at least the metatarsal figured by Pictet belonged undoubtedly to an Ungulate with only two metatarsals. At all events, these Eocene *Hyopotamidæ* seem to form a separate group; and as soon as their organization is better known, they will certainly be generically separated from the true *Hyopotami*. As the matter now stands, however, this *Hyopotamus* (*Cainotherium*) *Renevieri* is the smallest representative of the family, being hardly larger than a good-sized rat; the *Hyopotamus Gresslyi* had perhaps the size of our recent *Tragulidæ*. Between these small *Hyopotami* and the largest *Hyopotamus bovinus*, Ow., we have all the intermediate sizes distinguished as separate species under the names of *Hyopotamus porcinus*, Gerv., *crispus*, *borbonicus*, *velaunus*, Aym., *leptorhynchus*, *platyrhynchus*, *vectianus*, Ow., and finally *bovinus*. All these numerous species were, for the most part, founded merely on real or supposed differences in the size of the true molars, no author having figured or described any other part of the skeleton. Now, as every naturalist is aware, there can be no worse method of specific distinction than size, especially in richly developed families. Take our living Ruminantia, imagine them to be extinct, and some future palæontologist trying to give them generic and specific names by the characters of their upper and lower molars. I do not think he could arrive at any thing approaching truth. We may certainly form a large series of ruminant molars, entirely similar in shape, and ranging in size from the small *Antilope pygmæa* to the largest Antelopes and Bovidæ*, and then distribute all this assemblage of teeth into different species according to size; but the scientific value of such species would be indeed very doubtful. Still this is what we see constantly done in palæontology. In my opinion, we have, in most cases, not the least chance of hitting right in establishing specific distinctions on fossil remains; and most of the published species of extinct animals are certainly only productions of our palæontological methods of inquiry, which had no real distinction whilst living. On the other hand, it is just possible that the real number of so-called distinct species was greater than we can distinguish by fossil remains; at all events we have very little security that most of our specific distinctions correspond to the real state of things which existed in past geological time. Seeing the impossibility of arriving at any thing like an accurate knowledge of the specific distinction of extinct forms, it would be much more profitable to science if we were to give a pretty large range, as far as size is concerned, and concentrate all our discriminating powers on such characters as are really organic and fundamental, and may be taken as a basis for generic or subgeneric distinction. To found a new genus, a palæontologist is required to adduce some good reason for doing so; he is obliged to point out some organic difference, and this leads to a more complete study of the fossil forms; while the laxity with which we regard species requires, in a great majority of cases, no other reason than the phrase "this tooth *seems* to me to be specifically distinct from one already described," and a new name is formed which goes to the large number of others uselessly obstructing the science. Every one who has tried to ascertain the true organization of extinct types, and who is aware of our ignorance in this respect, will concur with my statement, that if, from the beginning of mammalian palæontology, all specific distinctions had been disregarded, and only the generic forms had been studied in detail, we should know much more about the extinct creation than we do now. The family of *Hyopotamidæ* may also serve as an instance of the unscientific methods which are paramount in palæontology. During the twenty-five years that the genus has been introduced to science, we have contrived to make more than ten species out of it; while nobody has ever cared to ascertain what its organization really was, and not a single bone has been figured up to this day.

---

* The Eocene *Cainotherium Courtoisi* from Vaucluse is identical with *C. Renevieri*, and therefore must share its fate, and be united to the *Hyopotamidæ*.

† Except *Dichodon* and *Merycopotamus*.

---

* The upper molars of some Ruminantia sometimes present distinctive characters in the form of additional pillars, but these are often present or absent in widely different forms.

This was the state in which I found our knowledge respecting *Hyopotamus*, when I determined to study it more completely than had been done heretofore. I knew that the principal collections, containing large materials for the study of this genus, were at Puy in Central France and in the British Museum. My kind friend Professor GAUDRY, of Paris, gave me letters of introduction to M. AYMARD, who is the possessor of the largest collection in Puy, and to M. ROBERT, Director of the public museum of the same town. I met with the most cordial reception from both these gentlemen; M. AYMARD especially, with the utmost liberality, placed the riches accumulated by him, during thirty years of diligent collecting, entirely at my disposal, and allowed me to make casts from every specimen I liked. This permission, which is so seldom accorded by private collectors, was of immense value to me, as my Plates could not be drawn at Puy, but had to be made in London. The same facility was afforded me by M. ROBERT; and I take the opportunity of expressing my warmest thanks to both these gentlemen. My thanks are also due to the artist, M. PELLEGRINI, in Puy, who made my casts, sparing no time and taking much trouble, the specimens from which the casts were taken being generally exceedingly brittle.

I found in the collection of M. AYMARD a large quantity of bones, which enabled me to get a complete conception of the skeleton of the interesting genus described in this paper. The bones proved that the *Hyopotamus* was one of the extinct Paridigitata with crescentic teeth, and had four completely developed digits on the fore and hind legs. The size of the teeth and bones enabled me to distinguish two or three species, as had been previously supposed by M. AYMARD. From Puy I came to London, where, by the kind permission of Professor OWEN and Mr. WATERHOUSE, the bones of the *Hyopotamus* contained in the collections of the British Museum were placed at my disposal. The jaws and bones from Hempstead, part of which were described by Professor OWEN in 1848 (Quart. Journ. Geol. Soc.), proved to be entirely identical with those found at Puy; so that the name of *Bothriodon*, which was applied to teeth and bones found at Puy, under the impression that they were distinct from those found at Hempstead, could not be retained, and the priority remains with the name *Hyopotamus* given by Professor OWEN to specimens from Hempstead. But, besides the bones from Hempstead, I found in the British Museum a number of well-preserved long bones, some metacarpals and metatarsals, as well as a well-preserved tarsus, which came from Hordwell from a true

Eocene bed, and were supposed to belong to *Hyopotamus bovinus*, under which determination they were placed in the Museum. At first I thought that these bones might really have belonged to the *Hyopotamus bovinus*, though the British Museum possessed no teeth of this genus from Hordwell. The long bones from Hordwell were strikingly similar to the *Hyopotamus* bones from Hempstead and from Puy; the calcaneus, astragalus, and phalanges were so entirely similar to *Hyopotamus* bones from these two localities, that it seemed impossible to doubt their generic identity. What looked very convincing also was the shape of the last, or ungual, phalanges. These ungual phalanges are very peculiar in the *Hyopotami* from Hempstead and from Puy; they resemble somewhat a large and thick human nail, and we know not a single living or fossil Ungulate having such peculiar ungual phalanges; however, even in this the animal from Hordwell entirely resembled the *Hyopotamus*. But the metacarpals and metatarsals of the Hordwell animal proved very different from any thing found at Hempstead or in Puy; they were considerably larger, and their shape was altogether different; the section was much more round, and the inferior or distal ends proportionately thicker. At first I could not find any plausible reason why the animal from Hordwell, being so similar to the *Hyopotamus* in all the long bones of the skeleton, should present this very striking difference in the shape of the metacarpals and metatarsals. But gradually, as I grew more familiar with all the peculiarities of these bones, and after having compared them with a large series of metacarpals and metatarsals of extinct and living Paridigitata, it became quite clear that the animal from Hordwell, although so similar in all its long bones with the *Hyopotamus* from Puy and Hempstead, differed widely from this genus in having only two metacarpals and metatarsals, and not four—being in fact didactyle, like the *Anoplotherium*. As we have never yet found at Hordwell a complete fore or hind foot in its natural connexion, I was very cautious in drawing my inferences from scattered and mostly broken bones; but the study of the relations of the carpal and metacarpal, and especially tarsal and metatarsal bones, gave altogether the same result; indeed there was no possible doubt that the animal from Hordwell could not have more than two complete digits to its fore and hind foot. Unfortunately I could not find any teeth belonging to the new animal whose almost entire skeleton was before me. The only authority who has noticed *Hyopotamus* teeth from a deposit in Hampshire is Professor P. Gervais. In his 'Paléontologie Française,' while speaking of *Hyopotamus* (p. 191), he tells us of having met *Hyopotamus* teeth, similar to those described by Professor Owen, in the collection of Bowerbank; "they came from a freshwater stratum in Hampshire." As the bed in which the bones of the new didactyle animal were found at Hordwell has really an outcrop in the New Forest, I suspect that the teeth seen by M. Gervais really came from this bed. However, the absence of these teeth, though much to be regretted, is not an obstacle to a complete knowledge of the new genus. The classification of Paridigitata is based entirely on osteological characters; and as nearly all the bones of the new animal from Hordwell are known, it is perfectly characterized, and, in my opinion, much better than many genera of which only the dentition is known. Besides, we must not forget that the *Hyopotamidæ*, as proved by the fauna of Mauremont and Egerkingen, are a true Eocene family; and the presence of a large representative of this family in the Upper Eocene of England is a very natural occurrence. I stated before that, even in the Mauremont and Egerkingen fauna, some of the *Hyopotamidæ* seem to have been didactyle; and we may take this as pretty certain as regards the small *Hyopotamus Renevieri*. The new didactyle animal from Hordwell is only a larger representative of these Eocene didactyle *Hyopotamidæ*; and we may expect that when its dentition is completely known it will very probably resemble that of the Eocene *Hyopotami* as found at Mauremont and at Egerkingen, and differ by its more ruminant-like premolars from the true *Hyopotami* which occur at Hempstead and in Puy. The presence of didactyle genera in Eocene deposits, while we find tetradactyle genera belonging to the same family in the Miocene, is no objection to the theory of descent as it is often argued by the adherents of the special creation hypothesis. The primary stock was undoubtedly tetra- or even pentadactyle; and under the incessant tendency to greater reduction and simplification of the limbs, which we witness in all Ungulata without exception, there were given off side branches which reached this utmost reduction of the limbs in the Eocene and became extinct, while the original unreduced stock continued to live till the Miocene period. A similar case may be imagined in relation to the recent Suinæ. There is no doubt that the *Dicotylidæ* represent one of the most advanced and reduced branches of the family of Suina; they practically reach nearly the same state of reduction of their limbs as the didactyle genera, their lateral digits being only useless appendages, having no importance for locomotion. Imagine that, by some geological change, the *Dicotyles* should become extinct in South America, while other continents should continue to be peopled by unreduced typical Suina: in this supposed case we should have an extinction of the filial branch, while the parent stock would continue to live and flourish. In the same manner I have little doubt that the didactyle *Hyopotamidæ* found at Hordwell and Mauremont descended from a tetradactyle stock, which very probably presented the same structure of the skeleton as we find it in the Miocene *Hyopotamidæ* from Puy and Hempstead*. And though the didactyle genus is found in strata older than those which gave us such complete materials for the restoration of the tetradactyle *Hyopotamidæ*, still, seeing the similarity of their skeleton, we may consider the didactyle genus from Hordwell as a reduced descendant of a form very similar in its skeleton to the *Hyopotami* of Puy and Hempstead.

Having ascertained the existence of this reduced representative of the family of the *Hyopotamidæ*, I could not, in view of the difference in the number of digits, permit the new form to remain in the genus *Hyopotamus*; and though I strongly object to the creation of new names, there is no help for it in this case, and a new generic division must be made to receive the didactyle Hyopotamoid from Hordwell, as well as similar forms which may turn up in the future. As the chief distinction of this genus is its didactylity, I propose to name it *Diplopus*, and to add to the special form found at Hordwell the name of M. Aymard, who has contributed so much towards the advance of our knowledge of this extinct group. I will therefore describe the animal from Hordwell under the name of *Diplopus Aymardi*.

---

* The probability is converted nearly into complete certainty if we consider that the reduced didactyle genus presents rudiments of two additional digits, the second and fifth.

From the point of view of pure descriptive osteology, it would be perhaps better to describe the *Hyopotamus* from Hempstead and Puy and the *Diplopus* from Hordwell separately. I have been prevented, however, by many reasons, from following this course, and I have preferred to give a comparative description of both genera: as the number of my Plates was limited, I could not figure all the bones belonging to both; and in the case of entirely similar bones, I gave preference to those which were better preserved. The present paper contains only the description of the long bones of the skeleton and of the limbs. I hope soon to be ready with the description of the vertebræ, skull, and dental characters. My best thanks are due to the officers connected with the Osteological and Geological Departments of the British Museum, as every thing which could in any way favour my studies was accorded in the most liberal way. My special gratitude is due to Mr. William Davies, of the Geological Department, to whose kindness and the interest he has taken in my work I owe very much. I am indebted to him for many valuable suggestions, and for the unremitting kindness with which he assisted me in looking over and over again through the rich stores of fossil remains contained in the galleries of the National Collection, and for aiding me in my comparisons in every possible way.

The Bones of the Skeleton.

The Scapula (Plate XXXV. fig. 1, $\frac{2}{3}$ nat. size).—This is a bone that has generally the least chance of being preserved fossil, owing to its flat shape and consequent thinness. Happily, however, thanks to the excellent method by which the bones from Hordwell were collected by Mr. Keeping, we have now in the British Museum, besides several detached fragments, a complete right scapula* from Hordwell, which belonged to the didactyle animal named by me *Diplopus Aymardi*. The chief characteristic of this fossil scapula is its enormous breadth compared with the antero-posterior length. No living Ungulate shows us such a broad scapula, the nearest approach to it being made perhaps by the scapula of *Hippopotamus*. Among the fossil Ungulata, the *Anoplotherium* (Blainville, Ost. *Anopl.* pl. iii.) comes even nearer to it, by the broad expanse of the horizontal part and by the large acromial process; there is, however, a marked difference between the two in the shape of the glenoid cavity, which is very oval in *Anoplotherium* and nearly circular in *Diplopus*. The coracoid process is not very prominent, but larger than in the recent Suinæ; it is separated from the glenoidal fossa by a slight notch, retreats a little backwards, and does not reach the level of the inner margin of the fossa. The fossa glenoidea is moderately deep, with a sharp margin raised all round.

The spine of the scapula is very high and sharp, set very obliquely on the horizontal part, and inclined to the outer side; its upper margin is rugose, but presents no flattening or expansion, as in many Ungulates of the Imparidigitate series. The pars acromialis is produced forwards in the same way as in *Anoplotherium*, the *Camelidæ*, and most Ruminants, but never in Pigs, where the spine rises very slowly from the neck backwards without any trace of an acromial process. The rising of the spine above the surface in *Hyopotamus* commences at a distance of 30 millims. from the glenoidal border; but the acromion is so produced forward that it reaches nearly to the level of the glenoidal cavity, overarching the neck of the bone. The supraspinous is a little smaller than the infraspinous fossa, but the difference is not important.

---

* As many bones were drawn without mirror (not reversed), it may happen that some of them described as right may be really left in the original. I shall, however, adapt my descriptions to the Plates, and describe the bones as they appear in the drawing.

In considering the very great breadth of the scapula of *Hyopotamus*, we must not forget that all Ungulata have a very large upper cartilaginous border, which is wanting in our fossil: the scapula figured by me belonged to a young individual; and we may safely infer that by the gradual ossification of the cartilaginous upper margin, the breadth would not be so disproportionate to its length as it is now. On the outer side of the neck of this scapula we see a pretty deep and large elongated fossa, found also on two other broken specimens. In general shape this fossil scapula agrees most with the scapula of *Hippopotamus*, by its great breadth and by the production of the acromial extremity of the spine, in which respect it also closely approaches some ruminants. With the Suinæ, however, we find no relation at all; and I particularly insist on this point, as, owing to the poorness of the Paridigitate types in our recent fauna, we are very apt, whilst studying fossil Mammalia with unreduced skeleton, to find resemblances with Suinæ even where they are very slight, just because the pig has one of the most complete (unreduced) skeletons among the living Ungulata.

Unfortunately I could not find in the collection of M. AYMARD, nor in that of the Puy Museum, a scapula of *Hyopotamus*.

Dimensions of the Scapula of *Diplopus Aymardi*.

	millims.
Height of the articular fossa	34½
Transverse breadth of the articular fossa	37
Height of the spine	31
Transverse breadth, including the coracoid process . . .	57
Breadth of the neck	47
Largest transverse diameter	190
Whole length	218

This was written and my Plates were drawn in London in the summer; but having in November last paid another visit to Puy, in order to examine the collection of Mr. VINAY, which I was prevented from seeing on my first visit, I found there a very good specimen of the scapula of *Hyopotamus*. The upper margin of the bone was broken, and only about two thirds remained entire; the spine of the scapula was preserved, although its acromial part was broken; and I could not ascertain if it was prolonged forwards in the same manner as in the scapula of *Diplopus*. My paper and Plates being already finished, I could not give a figure of this new specimen, and shall try to supply the want of it by a few explanatory remarks.

The scapula in the collection of Mr. Vinay belonged evidently to the largest species of *Hyopotamus* found at Puy, and in size equalled the scapula of *Diplopus* figured in Plate XXXV. The general aspect of this new specimen presented a great similarity to the one figured from Hordwell; beginning from the neck, the bone broadened rapidly to its upper and broken extremity, and acquired the same remarkable breadth which is so conspicuous a feature of the scapula of *Diplopus*. The spine of the scapula was also very oblique, inclining outwards as in the scapula figured in Plate XXXV. The fossa glenoidea had precisely the same exceedingly circular outline as is seen in the figured scapula; the coracoid process did not project much, and was recurved in the same characteristic manner. On the outer margin of the neck, however, where I found a deep fossa in *Diplopus*, the scapula from Puy presented only a flattening. In general the resemblance was as great as could be between two animals belonging to the same family but to different genera.

The Humerus.—I have been able to study many specimens of humeri belonging to *Hyopotamus* from the Isle of Wight, as well as from Puy, but unfortunately not a single complete one. As is generally the case with fossil humeri, their upper or proximal head, being very spongy, is destroyed during the process of fossilization, while the distal extremity is well preserved. Compared with a humerus from Hordwell, the humeri from Puy and Hempstead proved entirely similar to it; and as the Hordwell specimen, belonging to *Diplopus*, was the best preserved, I have figured it on Plate XXXVI. fig. 4, and my description of this humerus will apply equally well to both genera. As mentioned before, the proximal heads were broken in all specimens; but seeing the Anoplotheroid affinities presented by the distal extremity, we may presume that the proximal head also resembled rather the *Anoplotherium* than the Suidæ. In the first genus, as far as can be judged by a crushed *Anoplotherium* humerus in the British Museum, the great tuberosity did not overarch the bicipital groove so much as it does in Pigs and the Hippopotamus. We may, to a certain extent, infer the lesser overarching of the great tuberosity by marking the course followed by the crista anterior descending from this tuberosity, and which in *Hyopotamus* runs in the middle of the anterior surface of the humerus (fig. 4), and not so much on the inner side of it as in Suina. The deltoid ridge meets the crista anterior a little higher up than in *Anoplotherium*, nearly as in the Hog; and at the point of their meeting we see a conspicuous rugose flat surface for muscular attachment. The shaft of the humerus belonging to the *Diplopus* is very stout, thicker transversely than the humerus of a Reindeer, and much stouter in antero-posterior depth. The transverse section is not so regularly oval, but much more triangular than in Pigs or Ruminants, with the apex of the triangle turned forwards.

The inferior extremity of the humerus is very unlike that of any existing Ungulate, and presents a good intermediate form between the humerus of *Anoplotherium* and that of the Suina. As this inferior extremity of the humerus seems to me a very important part, especially as showing the modifications which a bone may undergo in adaptation to different conditions of life and organization, I must describe it at length.

Looking at the distal extremity of the humerus in the two series of fossil Ungulata, we shall see that its shape is at first exceedingly and typically different in Paridigitata and Imparidigitata. In the oldest Imparidigitata, as *Palæotherium*, and even in the living Rhinoceros, the distal extremity of the humerus is quite hourglass-shaped—that is, it looks as if two truncated cones were joined together by their apices. At the point of meeting we have a middle groove, from which the two horizontal cones thicken gradually in both directions, inwards and outwards. As we have every reason to suppose that *Anoplotherium* is the descendant of a very old type of Paridigitata, we may look to its humerus as giving us the typical form of the distal extremity of this bone in old Paridigitata. Now the distal extremity of the humerus of *Anoplotherium* is totally different from what we have seen in *Palæotherium*; the difference may be best imagined if we say that in lieu of the middle groove, where the two cones meet, we find in *Anoplotherium* a round bulging, which goes all round the distal extremity of the humerus (see Blainville, Ost. *Anopl.* pl. iii.). This middle bulging is very characteristic of all mammals in which the humerus is very movable upon the two bones of the antibrachium—so in Man, in most Carnivora, and in those Rodents which use their fore paws as hands. With the reduced mobility of the humerus upon the antibrachium, we remark a concomitant change in its distal extremity; the middle bulging recedes gradually to the outer half of this extremity and becomes much sharper, till at last, in animals with greatly reduced limbs whose humeri are fitted only for a simple sliding movement in one vertical plane (as in our modern Ruminants, and in some Rodents, as Hares), this round bulging of the *Anoplotherium* is reduced to a sharp ridge, which enters deeply into a corresponding groove on the proximal extremity of the radius (which must necessarily be adapted to all the modifications of the humerus). It is exceedingly interesting to follow this gradual modification, step by step, through all the intermediate stages presented by the *Chœrotherium* of Lartet, the *Hyomoschus crassus*, to our modern Ruminants, whose humeri show, instead of the Anoplotheroid bulging, an exceedingly sharp ridge fitting closely into a corresponding groove of the radius, and preventing any other movements save those in one vertical plane. It is interesting to notice that we see the same change going on in the Imparidigitata, though their starting-point, from the simple hourglass-shaped form of the humerus of the *Palæotheridæ*, is so different. In this series a rising appears gradually on the outer half-cone: in *Palæotherium* medium; this rising goes on increasing with the gradual reduction of the free movements of the fore limb in *Anchitherium* and *Hipparion*, till it reaches the state in which we now find it in the Horse; and in this last the distal extremity of the humerus is nearly like that presented by Ruminants; but as I have discussed this case in my memoir on *Anchitherium**, I will not return to it in this place.

---

* Mém. Académie de St. Pétersbourg, 1873.

In the humerus of *Hyopotamus* and *Diplopus* the middle Anoplotheroid bulging (Plate XXXVI. fig. 4, *a*) is much lowered, showing a step toward the condition seen in Pigs, in which it is raised into a very slight eminence. The inner margin of the humeral extremity (fig. 4, *b*) is produced a little downwards, but much less so than in *Anoplotherium*. The supinator ridge is not prominent, though its rugose surface testifies to the attachment of strong muscles. There is a very large intercondyloid perforation (*c*), into which the olecranon entered deeply, as in modern wild hogs. The breadth of the articular surface is very great comparatively to the transverse diameter of the whole distal extremity of the humerus. The humerus figured in Plate XXXVI. fig. 4 belonged to the didactyle form, *Diplopus Aymardi*; it is from Hordwell: besides this humerus I had many specimens from Puy and Hempstead; and as the two genera are confined to their respective localities, the *Diplopus* to Hordwell and the *Hyopotamus* to Puy and Hempstead, there is no danger of intermixing their fossil remains. The humeri of different size, which belonged to the tetradactyle *Hyopotamus*, are entirely similar to the one figured; the only difference which may be noticed consists in the fact that the distal articular surface is relatively larger in the *Diplopus* than in *Hyopotamus*, as seen by the fact that in the three humeri of nearly equal size measured by me, the breadth of the articular surface is 42 millims. in *Diplopus*, and only 32 and 35 in two humeri of *Hyopotamus*.

Dimensions of the Humerus.

	Diplopus Aymardi. (Fig. 4.)	*Hyopotamus.*	
	Hordwell.	Hempstead.	Puy.
Largest transverse diameter of the distal extremity........	54½	55	54
Transverse breadth of the articular surface	42	35	32
Vertical height, articular surface, internal border (*b*)	32	31	28
Vertical height, articular surface, external border	24	23	22½
Vertical height at the middle groove (*a*)	23	21	20
Transverse diameter of the shaft (inf. $\frac{1}{3}$)	28	22	20
Antero-posterior diameter	39	27½	

The Ulna.—The antibrachium of *Hyopotamidæ* consisted of two completely separate bones, and there is no trace of their having been immovably connected together, as in nearly all living Ungulates. I had several specimens of this bone from Puy, and from the English localities of Hempstead and Hordwell; all, however, were more or less broken, save a splendid specimen from Hordwell in the British Museum. This right ulna (Plate XXXVI. fig. 1) fits the humerus figured in the same Plate (fig. 4) as exactly as if it came from the same individual. I will give the description of this complete specimen, and state the differences it presents from other ulnæ from Puy; the complete specimen figured in Plate XXXVI. belonged to the didactyle *Diplopus*. The shape of this bone in our didactyle genus is very striking from its extreme flatness and breadth; it is much arched forwards, and this curvature reminds one of the ulna of Suinæ. At the upper part we see a very large and broad olecranon, which differs slightly from living Ruminants and Pigs by its greater transverse breadth, and by the more projecting hook of the fore part, which entered deeply into the intercondyloid perforation (fig. 4, *c*) of the humerus. The fossa sigmoidea is uninterruptedly united on the inner side to the radial facet, while its outer part presents a deep *échancrure*. The outer radial facet of the ulna is not united to the fossa sigmoidea in the *Diplopus*, though it is so in the smaller *Hyopotamus* from the Isle of Wight and from Puy (fig. 2, *or*). Both articular facets for the radius are nearly in one plane, whilst in Ruminants the outer facet projects much more forwards than the inner. The section of the ulna of *Diplopus* gives us a figure like a flat or low triangle, not quite regular on its external border. The posterior surface (Plate XXXVI. fig. 1″, *p*) of the ulna is the large basis of the triangle; the obtuse apex (*a*) presents a rugose ridge, seen in fig. 1′, running on the fore part of the ulna, and by which it is pressed against the radius; the sides of the ulna are inclined planes, uniting the extremities of the base to the apex. Just below the second third of its length the three planes of the triangular ulna begin to narrow whilst descending to the distal extremity, which retains the same triangular outline. The inferior extremity is cut nearly at right angles by the facet for the outer bone of the carpus.

If we compare smaller ulnæ from Puy and the Isle of Wight we shall see some differences not only in the shape of the sigmoid fossa, but likewise in the transverse section of the ulna. In some of the ulnæ, like the one figured from Puy (fig. 2), the lower and fore part of the fossa sigmoidea is much produced forwards, forming a sort of prominent bridge between the inner and outer radial facets of the ulna; the production of this connecting bridge creates a deep fossa in the middle of the anterior surface of the ulna. Having examined this part of the ulna in a large number of recent Suina, I found it very variable, and therefore cannot lay too great a stress upon it in the *Hyopotamidæ*. But besides this, the ulnæ from Hempstead and Puy, belonging undoubtedly to *Hyopotamus*, have a very different horizontal section, and they are by no means so much flattened as the ulna of the *Diplopus*; this difference is most clearly seen by comparing the horizontal sections of both ulnæ taken about the middle of the bone. The species from Puy have a much deeper and sharper posterior edge (fig. 2′, *p*), which is nearly absent in the *Diplopus*. Unfortunately I have not found a single entire ulna of the *Hyopotamus*, though I have seen a large number of broken specimens from Puy and the Isle of Wight. Comparing these broken ulnæ with the one figured, I found some notable differences in details, which will be clear to the reader by comparing the figure of a part of the ulna from Puy and its transverse section (figs. 2 & 2′) with that of the ulna from Hordwell (figs. 1 & 1′). The differences extended further than the shape of the sigmoid cavity, as the following Table of measurements will show.

Dimensions of the Ulna.

	Diplopus (fig. 1, Plate XXXVI.).	*Hyopotamus.*			
		Puy (Plate XXXVI. fig. 2).		Hempstead.	
Total length along the curvature	270				
Posterior chord	254				
Greatest breadth at the radial facets	32	30	26	25	30
Breadth at the middle	33	18	..	..	17
Antero-posterior diameter (at radial facets)	22	24	23	25	30
Antero-posterior diameter (middle)	12	19	..	..	20
Transverse breadth, inferior extremity	16				
Antero-posterior diameter, inferior extremity	11½				
Antero-posterior diameter from the point of olecranon to the posterior surface	48	..	..	..	46

The distal end of the ulna of *Diplopus* is triangular, with a slightly excavated triangular facet for the pyramidale of the carpus. I have not the pisiform bone; but as there is no facet on the posterior side of the distal end of the ulna, this bone probably did not articulate with the ulna, but exclusively with the pyramidale.

The great difference in the horizontal sections of the ulnæ of both genera (fig. 1″ and fig. 2′, Plate XXXVI.) is produced by the great flattening of the ulna of the didactyle *Diplopus*. The section of the ulna of a hog taken in the middle will give nearly the same figure as the section of the *Hyopotamus* ulna (fig. 2′). The same letters mark the corresponding parts in both sections. As an instance of a greatly compressed ulna, I may adduce the ulna of *Hyomoschus*; it is so compressed laterally that its antero-posterior depth is ten times as large as the transverse breadth; and the whole bone, from its radial articulation downwards, looks like a knife-blade with its sharp edge turned forwards towards the radius.

The Radius (Plate XXXVI. fig. 3).—I was not fortunate with this bone, as I have not a single complete specimen; even fragments are rare.. I found, however, in the collection of the British Museum an upper half and a distal extremity of a radius from Hempstead which belonged undoubtedly to *Hyopotamus*. I possess also the same parts from Puy, and they entirely agree with the English specimens.

The proximal extremity of the radius is always shaped so as to fit the distal end of the humerus, and their variations are always correlative. For this reason the radius of *Anoplotherium*, constructed to fit the very peculiar distal end of its humerus, is made on a pattern exceedingly different from that of all other Ungulata, and shows a striking likeness to the proximal extremity of the radius of a carnivore, especially the Dog; but in *Hyopotamus* we find a more Ungulate-like radius. Instead of the great oblique middle fossa of the *Anoplotherium*, we see in *Hyopotamus* a shallow and broad groove (fig. 3, *a*′), made to fit the middle bulging (fig. 4, *a*) of the distal extremity of the humerus. The inner part of the proximal surface is a plane (Plate XXXVI. fig. 3, *b*′) less inclined than in *Anoplotherium* (Blainv. Ost. *Anopl.* pl. iii.), but much more so than in Pigs, owing to the greater downward production of the inner condyle of the humerus (Plate XXXVI.

fig. 4, *b*). The two posterior small fossæ for the radial facets of the ulna are not very deep; they are separated by a posterior bony projection, which entered, or is thrust under, the connecting bridge of fig. 2, *cb*. We have no direct means of ascertaining the curvature of the radius, but it is given to us by the shape of the ulna (fig. 1), so that, at least in *Diplopus*, the radius must have been considerably arched forwards.

The distal extremity (fig. 3′) of the radius is very unlike that of any existing Paridigitate. In these we see generally on the distal end of the radius two longitudinal excavated facets, separated by an oblique prominent ridge running in the interspace between the scaphoid and the lunare (see Blainv. Ost. *Anopl.* pl. iii.); we have no trace of this ridge in *Hyopotamus*. The inner half of the distal end (fig. 3′, *i*) is occupied by the oblique convex facet for the scaphoideum; the outer half presents a concave anteriorly broad facet for the lunare; this bone, having a very oblique position in the carpus, encroaches by its posterior narrow prolongation upon the scaphoidal half of the distal extremity of the radius. Both facets are separated anteriorly by a deep groove, seen opposite the number 3′ of the figure. The difference from the radii of all other Ungulata is considerable. To the external straight truncated surface (fig. 3′, *ex*) the distal extremity of the ulna was articulated; but I have had no specimen of *Hyopotamus* showing this distal end of the ulna.

The radius of *Hyopotamus* was articulated (as in all Ungulates having a completely developed ulna) only with the two inner bones of the carpus, the scaphoid and the lunare, while the outer bone, the pyramidale, is taken up entirely by the distal extremity of the ulna. All existing Suidæ show us the same relation; but in *Dicotyles*, whose skeleton is a little more reduced than that of the typical Pigs, we see that the distal extremity of the radius grows broader in consequence of the reduction of the ulna; and, besides its two typical carpal bones, makes an encroachment upon the outer one, the pyramidale. With the still greater reduction of the ulna in most Ruminantia, the radius goes on increasing, and not merely touches the pyramidale, as in *Dicotyles*, but takes the whole half of its upper surface for its own support, while the reduced ulna is pushed back to the posterior half of the pyramidale. In consequence of this changed relation between the carpal bones and the radius, the distal extremity of this bone in Ruminants acquires at its outer border an additional facet for the pyramidale, of which not a trace is to be seen in *Hyopotamus*. We may mention as another peculiarity of the distal end of the radius of *Hyopotamus*, the entire absence of any styloid process or prolongation of the inner border of the distal end of the radius, which is well seen in other Paridigitates, as *Anoplotherium* and *Hippopotamus*. Specimens of the distal and proximal extremity of the radius which I possess from Puy agree in every particular with the one described from Hempstead.

Dimensions of the Radius.

	Hyopotamus.	
	Hempstead.	Puy.
Transverse breadth of the proximal extremity......	30	32
Antero-posterior depth of the upper surface........	20	19
Transverse breadth of the distal extremity. These extremities seem to be epiphyses of radii of young individuals	32	30

The Femur.—Of this bone I had a complete specimen from Puy (fig. 5, Plate XXXVI.), an upper half of a smaller species from Hempstead (fig. 6), and a lower half (Plate XXXV. fig. 2) from the same locality, but belonging evidently to a larger individual or species than the upper half. I had no femur from Hordwell, and consequently this bone is unknown in *Diplopus.*

Confining our comparison only to the Paridigitate series of Ungulata, of which *Hyopotamus* is one of the old representatives, we find in our fossil femur characters that are very common to all the members of this division. In comparing the ruminant and non-ruminant Paridigitata, we find that the femur in the Suina has a more complete spherical head supported on a pretty distinct neck, the great trochanter rising very slightly or not at all above the level of the femoral head, and a small (or inner) trochanter not very prominently developed, and often consisting merely of a rugose thickening at the antero-posterior edge of the superior half of the femur. The general shape of the bone is very round in *Dicotyles*, more flattened in other pigs, and slightly arched from behind forwards. Both edges of the anterior part of the distal articular surface (rotular surface) are alike, while the internal condyle is thicker than the external; the transverse breadth of the trochlear surface for the patella is proportionately broader in comparison with the entire thickness of the distal end than in Ruminantia (*Dicotyles* forms an exception to this rule, and the rotular breadth of its femur presents the same relation to the whole thickness of the distal end as in Ruminantia). Now the femur of *Hyopotamus* shows characters that are common to both divisions of Paridigitata. The head of this femur is supported on a neck (fig. 6) even more distinct than in the Suina, and approaching that of *Hippopotamus.* The great straightness of the whole femur reminds us also of this last genus. The spherical head is provided with a deep pit for the round ligament, which is absent in *Hippopotamus.* This round articular head is connected with the prominent small (inner) trochanter by a very sharp ridge, as in some Suina, only the ridge is higher and sharper (fig. 6′). The bridge of bone (fig. 6, *a*) connecting the head of the femur with the great trochanter is much contracted in the middle, and lowered in such a way that both articular head and great trochanter rise considerably above the level of the connecting bridge—a character very general among the Paridigitata, with the exception of the *Camelidæ*, in which the superior end of the femur is shaped on a plan entirely different from other Ruminants, presenting a great resemblance to the Imparidigitata (*Rhinoceros*) in the breadth of the connecting bridge and the shape and position of the great trochanter. The shape of the femur in *Hyopotamus* (fig. 5) is remarkably uniform in its thickness, is exceedingly straight, and presents on its posterior surface, above the internal condyle, no deep pit for the plantaris muscle, but a simple rugosity, as in hogs. Some comparative anatomists seem to attach a great importance to this fossa, though I cannot do so, seeing that this fossa is developed or absent in animals belonging to both series, Paridigitata and Imparidigitata. For instance, it is very large in the Horse, but absent in the Rhinoceros; developed in most Ruminants and *Hippopotamus*, but absent in *Camelidæ* and *Suidæ*, where we find, in place of the pit, a rugose surface for the attachment of the same muscle.

The fore part of the distal extremity (Plate XXXV. fig. 2), as in most living Ungulates of both series, with the exception of the Suinæ, *Hyomoschus*, and some Ruminants, has a more developed internal rotular edge, though the difference in thickness of the internal and the external edge is not carried to such a degree as in Bovidæ and Horses, but is comparatively slight. The internal condyle is also a little thicker than the external.

The lower extremity (Plate XXXV. fig. 2) of the femur from Hempstead may belong to *Hyopotamus bovinus* by size: this last specimen was kindly lent me by the Museum of Practical Geology in Jermyn Street; it is figured of the natural size.

Dimensions of the Femur of *Hyopotamus*.

	Puy.	Hempstead.	Hempstead (Plate XXXV. fig. 2).
Length	283	?	Transverse breadth of the upper broken end ..36
Transverse breadth of the proximal extremity between the articular head and the great trochanter..	62	47	Antero-posterior depth.....................25 Transverse breadth of the distal end ....61 Breadth of the rotular surface 26

The Tibia (Plate XXXVI. fig. 7).—I had for the study of this bone two nearly entire specimens from Hordwell, belonging to the large didactyle form *Diplopus*, and some incomplete upper and lower ends from Puy; these last undoubtedly from the tetradactyle *Hyopotamus*, as no *Diplopus* is found at Puy. The tibia of the *Diplopus* from Hordwell approaches very nearly in length to that of a Reindeer, showing that the two-toed *Diplopus* must have been very high on the hind legs, and the long metatarsals confirm this view. The general shape of this tibia is triangular from the upper part down to the distal extremity, and not so much rounded in the lower half as the tibia of the Suinæ. The crista anterior is not very high, with only a slight patellar depression on its fore part, much shallower than in Pigs. The shaft of the whole bone is very straight; the outer edge, facing the fibula, is exceedingly sharp, while the inner is more rounded. The distal end (fig. 7′) shows a very rectangular outline, with two straight deep grooves for the upper pulley of the astragalus. The inner distal process of the tibia, or the so-called inner malleolus, which holds the astragalus from the inner side, is much longer than in Suina, approaching more to the size it exhibits in most Ruminants, with the exception of *Tragulina*, as these last have an exceedingly short inner malleolus. The outer distal edge is truncated somewhat obliquely, and has a groove in the middle for a corresponding convex ridge on the inner surface of the fibula, which fits the tibia in the same way as in Pigs, and being produced distally together with the internal malleolus, firmly clasps the astragalus (figs. 7 & 7′, Plate XXXVI.). The posterior surface of the upper half of the tibia is very flat, showing some oblique, rough bony ridges for muscular attachment.

The upper or proximal articular surface for the femur presented more resemblances to Suinæ than with Ruminantia, especially in the deep outer groove for the muscular tendon, though the patellar fossa on the fore part of the crista anterior is shallower than in *Sus*.

In the broken upper and lower halves of the tibiæ of *Hyopotamus* I find no difference from *Diplopus*, save that of size.

Dimensions of the Tibia.

	Diplopus (fig. 7, Plate XXXVI.).	*Hyopotamus.*	
	Hordwell.	Puy.	Hempstead.
Length	280	240	
Transverse breadth, proximal extremity	68	55	
Transverse breadth, distal end	43½	31½	36

The Fibula.—Before describing this bone in the *Hyopotamidæ*, we must call to mind the principal differences it shows in the two series of Paridigitata and Imparidigitata. The proximal end is wanting in all our specimens; but this is not of any consequence, as all the chief characters are presented especially by the distal extremity. In all Imparidigitata which possess a complete fibula, this bone is applied to the outer side of the tibia, forming at the distal extremity the malleolus externus (Plate XXXVI. fig. 7); this distal extremity is truncated obliquely in such a way that the inner surface of it articulates only with the astragalus, forming its outer boundary; the fibula can never touch the calcaneum[*], as this bone has no special surface developed on its upper lateral part to receive the distal end of the fibula. On the contrary, in all Paridigitata the fibula being applied in the same way to the tibia, presents at its distal end *two* articular facets for the articulation with *two* tarsal bones. The inner surface of the fibula (Plate XXXVI. figs. 7 & 7′, and Plate XXXV. fig. 3, nat. size) is pressed against the astragalus; but its inferior extremity does not thin out, as in Imparidigitata, but is truncated at right angles, and provided with a special articular facet for an articulation with the outer wall of the calcaneum. We shall see hereafter that this outer wall exists perhaps also in the Imparidigitata, but that it is thrust under the astragalus; and this seems to be the cause why the fibula of the animals belonging to this series cannot articulate with the calcaneum.

[*] *Macrauchenia* seems to present the single exception to this rule. The calcaneum of *Macrauchenia* is not known.

The fibula of *Diplopus* (Plate XXXVI. fig. 7, and Plate XXXV. fig. 3) is shaped entirely in conformability with the Paridigitate type; it is a considerably reduced bone, with a very thin shaft; the distal extremity, however, is widened considerably in the antero-posterior direction. The inner surface of this broad (it would be more correct to say deep, as the fibula is widened from before backwards) distal extremity (Plate XXXV. fig. 3) is shaped on the same pattern as in the Suidæ, presenting a more uniform arched and slightly raised platform pressed against the astragalus, and not a deep semicircular notch as in Ruminantia. (In these the shaft of the fibula is generally mostly reduced to a mere tendon, but its lower extremity remains under the name of the so-called "*osselet péronéen.*") The articular end for the calcaneum (fig. 7′) presents a very deep and narrow facet, which occupies the whole antero-posterior extent of the distal extremity of the fibula. The anterior part of this calcaneal surface is slightly convex, the posterior concave.

I have found at Puy many distal extremities of the fibula, which belonged undoubtedly to *Hyopotamus*; and even this bone bore a great resemblance to the same part of *Diplopus*. This is another fact testifying to the very close relationship of both genera, notwithstanding the difference in the number of toes. A resemblance which holds good even in such slight details is a conclusive proof that both genera—the *Diplopus* from Hordwell and the *Hyopotamus* from Puy (and Hempstead)—belonged to the same family, and that one may be considered the reduced form of the other, notwithstanding the seemingly adverse fact that the reduced form is met with in the Upper Eocene, and the more complete in the Lower Miocene. This last certainly had Eocene ancestors, which may be considered to have given rise to the reduced form, while they continued to live themselves until the Miocene period.

Dimensions of Fibula, distal end.

	Diplopus (Plate XXXV. fig. 3, nat. size).
Antero-posterior diameter of the upper broken end. .	8
Thickness of the same	4
Antero-posterior diameter of the distal end	29, 26½
Thickness of the same	9

General considerations on the carpal and tarsal, metacarpal and metatarsal bones in Hyopotamus, Diplopus, *and other Paridigitata.*

If, generally speaking, the long bones of the limbs in Ungulata often present but few characters decisive enough to tell us at once the natural series to which an Ungulate mammal belongs, the converse is the case with the smaller bones of the extremities, which have therefore a great systematic importance. We may very often know most of the long bones of the skeleton, the scapula, the humerus, the antibrachium, the tibia and fibula of a fossil Ungulate, without being able to determine quite certainly the natural series to which it belonged; nay, even more, we may discover the skull and the complete dentition without being made much wiser by it. The history of palæontology swarms with such examples; but the discovery of a single carpal or tarsal bone very often clears the whole question, by showing in the most unmistakable manner the true affinities of a fossil form. Seeing this great importance of the carpal and tarsal, metacarpal and metatarsal bones, I feel obliged to enter into more minute details than I have done in the case of the long bones of the limbs; and I shall try to show how constant and important are the characters which we may derive from the study of these small bones, and what excellent data they may furnish towards a complete understanding of the development in time of the large and extensive group of modern Ungulata. As in one of my former memoirs* I tried to follow this course in reference to the Imparidigitata, I will confine myself in this paper only to the Paridigitate series. As the chief differences for subgeneric or specific division of the *Hyopotamidæ* are furnished by the bones of the feet, I shall describe these first, leaving the skull and the dental characters to be treated afterwards.

Although I found at the British Museum and in the private collection of M. Aymard at Puy very extensive materials for the restoration of the fore and hind feet, still it is to be regretted that as yet we have never found a complete fore or hind foot, in its natural connexion, belonging to the same individual; still less was there a chance of finding the bones associated in an undoubted manner with a certain set of teeth: all bones of the *Hyopotamus* occur very much scattered, and no complete skeleton belonging to one individual has ever been found, at least to my knowledge. The happy circumstances which enabled Cuvier to refer, without any doubt, certain sets of bones to certain skulls (as whole skeletons were sometimes found in the gypsum of Montmartre) did not favour my research. But if the actual connexion of specific bones and teeth should still remain not entirely cleared up, the general osteology of the genus will not in the least suffer by it; and with the materials I had at my disposal, I am conscious of being able to reconstruct both generic forms in a very satisfactory manner, though even for the carpus I had no complete set of bones belonging to one individual. But in certain series of animals the peculiar form and general relations of these bones are so constant, that we may expect variations only in the smallest particulars; so that the general structure of the feet and the mutual relation of the carpal and tarsal bones between themselves, and to the bones of the metacarpus and metatarsus, may be considered undoubtedly settled for the *Hyopotamidæ*. To make my description more clear to the reader, I will take care to make comparisons with animals accessible to every naturalist; and I think that for the full comprehension of the relations of these irregular bones drawings are wholly inadequate, and a direct comparison with the feet of a pig and a ruminant should be resorted to.

Notwithstanding the great external diversity of the recent Ungulata, taking both series of Paridigitata and Imparadigitata, where we meet with animals so different in their aspect, habits, and size, running through all the intermediate stages from a rabbit

---

* "Sur l'Anchitherium," Mém. Acad. St. Pétersbourg, 1873.

(*Hyrax*) to the largest Rhinoceros, Hippopotamus, or Giraffe, their osseous structure is exceedingly uniform and simple, presenting only two chief types, which are completely defined by the terms Paridigitata and Imparidigitata. Beginning with the oldest Eocene deposits, these two types are entirely separated by the structure of their skeleton, and we have not a single living or fossil form that could truly be considered a link between these two typically different series. I have little doubt that all Ungulates must have sprung from some common form; but if so, their division was effected in very ancient times, perhaps in the early Cretaceous period. I say *early*, because just at the close of the Cretaceous period, in the lignites of Soissons and the calcaire grossier, or in beds that are contemporaneous with them, we find large Mammalia of both series with a very reduced skeleton. Considering the rate at which the reduction of the limbs in Ungulates proceeded in the Eocene, Miocene, and Pliocene periods, we are obliged to grant a long time for the branching off of the two series of Ungulates from a common pentadactyle form, and the subsequent reduction of each branch to the three- and two-toed forms, met with in ancient Eocene beds.

In the recent period, notwithstanding the great diversity and very wide distribution of Ungulates, they present an extreme poverty of type. The Imparidigitate series is strikingly poor, not only in generic but also in specific forms; they go on evidently declining from the Eocene; and in the recent period we have only three different types of these animals—the *Equina*, *Rhinocerotina*, and *Tapirina*; and even these three present such a fundamental resemblance in the structure of their limbs and skeleton, that no reasonable doubt can be entertained as to their descent from a common progenitor. On the other hand, the Paridigitata, though presenting in the recent period an exceedingly great diversity of size and habits and a great variety of specific forms, outnumbering tenfold those of the Imparidigitata, present also only two distinct types, Ruminantia and Suina; and, even in these, the fundamental structure of the limbs and skeleton is so uniform that we may safely infer their descent from one common form. In the present memoir I have taken up only the second series, the Paridigitata; and I shall try to show, as clearly as possible, the common bond that holds them all together. I shall point out that the uniformity of this fundamental type adapted to different conditions of life is so great that, notwithstanding extreme diversity of size, difference of habits, aquatic or terrestrial life, we may trace through the whole complexity of these diversified forms not only the number and shape of their carpal and tarsal bones, but even each separate facet of these bones, and point it out as clearly in the reduced limb of a land Antelope as it is displayed in the complete unreduced limb of the aquatic Hippopotamus. Further, I shall try to show that this uniformity of type holds good, not only of the living, but also of the extinct forms of Paridigitata.

If we cast a glance on the first section of the fore foot, or the carpus, of any Paridigitate whose skeleton has not suffered too considerable a reduction (as for instance a Pig or Hippopotamus, Plate XXXVII. fig. 1), we shall find that it consists of two rows, containing seven small irregular bones, with an additional one (the pisiform) on the outer end of the upper row. We find in the upper row, beginning from the inner side, the scaphoid, lunar, pyramidal, and pisiform; in the lower, trapezium, trapezoid, magnum, unciform. In all extinct Paridigitata, even those with a very reduced skeleton, we find the full number of these carpal bones (so in *Anoplotherium*, *Xiphodon*, *Hyopotamus*, Plate XXXVII. figs. 2, 3, 20); and, only in consequence of the still greater reduction of the limbs, in some recent Ungulata one of the carpal bones (the trapezium) seems to be entirely lost, while another (the trapezoid) becomes confluent with the magnum; that the trapezoid is not lost but is confluent with the os magnum, is shown by the two different points of ossification in the cartilage of the os magnum in young sheep. As we shall hereafter see, the number and shape of the carpal and tarsal bones of all animals belonging to the Paridigitate series present an extreme uniformity, individually as well as in their relation to one another and to the metacarpal and metatarsal bones; and this similarity is indeed so great that we cannot explain it in any other way than by community of descent. The extreme constancy in the relations of these bones in all Paridigitata being ascertained, the problem which is unavoidably presented to the mind of the observer may be stated thus:—Very irregular small bones, intended to constitute a movable articulation between the long bones of the extremity and the metatarsals and metacarpals, arranged themselves in a certain way in reference to one another and to these metacarpals and metatarsals; this arrangement remains the same in all Paridigitata, recent as well as fossil, notwithstanding the greatest diversity of form, size, and habits of life; and if some slight change is to be seen, it is due clearly to the overdevelopment of certain digits and consequent reduction of others; but in all cases the reason of change is at once apparent: how can such similarity in animals so entirely different be explained? To all naturalists who accept the gradual descent and differentiation of all Paridigitata from one common form, the fact must appear as a perfectly reasonable and intelligible one. If the immediate progenitor of the Paridigitates presented the given arrangement of the carpal and tarsal bones, then, at the gradual differentiation of this type, every small change in one bone called forth a corresponding change in all its neighbours. And as the link which connects all the forms together was never destroyed, and the changes were slowly going on, we meet now, in the extremely differentiated descendants, a unity of organization which was inevitable if all these forms descended from one common progenitor. But if, leaving the point of view of evolutionists, we look at the matter on the special-creation principle, this similarity of structure in animals so widely different is really an awkward fact. To the supporters of special creation the question presents itself in its simplest form thus:—We have now on the earth a large assemblage of Paridigitate mammals, presenting widely diversified generic and specific forms, fitted for the most different conditions of life, some leading an amphibious existence, sharing the large streams with Crocodiles, while others inhabit inaccessible rocks or burning sand plains, some heavy and sluggish, others light and swift, &c.; and yet the creative force, in calling separately into existence these diversified forms, made them all on one plan, and this to such an extent that even the seven bones of the carpus and tarsus, notwithstanding their irregular shape, were always arranged in the same way, so that a certain facet of one bone always touched a certain particular facet of another, and never otherwise. That this could really occur in every separate case of creation, is almost as probable as that seven dice thrown out of a dice-box should give us the same number of points, similarly arranged in a hundred successive throws. Notwithstanding the thousands of different relations which might exist between such seven multangular bones, we get always only one; and in the whole range of living and extinct animals we see no exception to the common rule of typical arrangement of the carpal and tarsal bones. The point at issue is, can this uniformity be accounted for by the principle of special creation, or by the theory of descent and modification? No naturalist can in our time hesitate between the two; and while all the adduced facts are wholly inexplicable by the first theory, they seem most natural in the light of the second. We may still not be fully informed as to all the true causes which induced the variation and consequent differentiation of animal types; but the principle of descent must be conceded as the only one by which all future researches into the structure of the extinct world must be guided.

I have mentioned chiefly the carpal bones; but the study of the tarsus leads to precisely the same result, and the likeness of the tarsal bones in all Paridigitata is perhaps even more striking than that of the carpals. All Paridigitata have a calcaneum with a special facet for the fibula, an astragalus with a double pulley, a cuboid supporting the fourth and fifth digits, and a navicular, with three cuneiforms, for the support of the third and second digits; the first digit being always lost, its tarsal bone is gone to give support to the second toe, or, if this be lost, to the rudiment of it. We shall see these relations by-and-by, when we come to the special description of the tarsal and metatarsal bones.

The Carpus of Hyopotamus, *or the Four-toed Form.*

In describing the bones of the carpus of the *Hyopotamus*, I will try to confine my comparisons exclusively to the nearest living relatives of the extinct genus, as only such likeness and difference between nearly related forms belonging to one natural series can be of any immediate use for our purpose. Resemblances to the bones of animals belonging to other series are mostly only analogies, not homologies; and if some similarities which we may find to the carpal bones of animals belonging to the other natural series of Imparidigitates are of importance as testifying their common descent from some ancient form, still we lack so completely any links between these two series (which are entirely distinct from the oldest Eocene deposits) that it would be idle to speculate about their relation on such trifling characters as these. I will therefore as much as possible confine myself to the series of Paridigitata. The carpus of *Hyopotamus*, like that of all Paridigitata, consisted of eight typical bones, four in each row; of these eight bones I have only five, the trapezium, pisiform and magnum being absent from all the collections I had an opportunity of studying; but their absence will not interfere much with the complete restoration of the fore foot.

The *scaphoid* (Plate XXXVIII. fig. 5, *s*) is not very different from the corresponding bone of the pig in its upper part; but the general form tends more towards the *Hippopotamus*. The proximal surface reminds us of the same surface of the *Anoplotherium* (Cuv. Oss. Foss. v. p. 217), and shows a very shallow platform, sloping radially; in correspondence with this, the inner part of the distal extremity of the radius (articulating with the scaphoid) is also very flat. In our recent Suidæ, this proximal facet of the scaphoid has a great rising on the fore part and a deep excavation behind; and, correspondingly, the extremity of the radius is more deeply excavated, and the interlocking of the two is firmer.

The distal surface of the scaphoid in the *Hyopotamus* is very distinct from the same surface in the pig, and reminds us more of what we see in *Hippopotamus*; namely, it is divided by an oblique ridge into two slightly concave facets, of which the radial or posterior facet articulates with the trapezoid (Plate XXXVIII. fig. 5, *t*), and the ulnar or anterior reposes on the os magnum (Plate XXXVIII. fig. 5 and Plate XXXVII. fig. 20), which being absent, its place is left blank in our figures.

The posterior extremity of the scaphoid is elongated into a thick recurved portion, which bends inside the carpus. The inner or ulnar surface exhibits nothing particular; its upper margin is occupied by a long narrow facet for articulation with the lunare. The outer free surface is uniformly rounded.

Dimensions.

Length antero-posteriorly . . .	30 millims.
Height	16 ,,

The scaphoid (from Hempstead) described above belongs to the tetradactyle form of the *Hyopotamidæ*, or to the genus *Hyopotamus*; but I have found in the collection of the British Museum another scaphoid bone (from Hordwell), which I may with great probability refer to the didactyle form called *Diplopus*. This scaphoid is very different from that just described; and all the differences point to a reduction of the foot. Its proximal surface does not slope outwards, but is perfectly horizontal, with a transverse rising in the fore part, a hollow in the middle, and an elevated posterior border; such a surface of the scaphoid ensured a firmer interlocking with the radius. It reminds one strikingly of the same surface in the *Anchitherium*; and it is possible that the distal end of the radius in the *Diplopus* was shaped on the Cameline type, which is very similar to that of a Horse or *Anchitherium*.

The distal surface is not divided into two facets, but is uniform, like the distal surface of the same bone of a pig; and this is very intelligible, seeing that the trapezoid, having no complete second toe to support (as in *Hyopotamus*), did not press on the distal surface of the scaphoid, leaving there such an impression as it did in *Hyopotamus*.

The *semilunar* (Plate XXXVIII. fig. 5, *e*, and Plate XXXVII. *l*).—I had several lunar bones of different sizes from English deposits as well as from Puy. Those from the latter place agree entirely with smaller lunars from Hempstead; and we may safely infer that they belonged to the *Hyopotamus*.

In general shape the lunar has the same character as the same bone in other Paridigitata, especially the Suina—with this difference, that it is relatively much thinner and higher in *Hyopotamus*, as might be expected from the form of all the bones of the skeleton, showing that the Hyopotamidæ had a much more elegant and higher skeleton than our recent Suina. The proximal or upper surface of the lunar, which articulates with the outer half of the distal extremity of the radius, has a considerable rising in the fore part and an excavation behind; this upper surface, looking on it from above, has a very oblique direction inwards; this is effected in such a way that the radial upper margin of the lunar is pressed closely to the scaphoid, while there is a great interval between its upper ulnar margin and the pyramidale: a glance at the proximal surface of a pig's carpus will explain this disposition much better than long descriptions.

The distal surface of the lunar is prolonged into a prominent beak inserted between the os magnum and unciforme. This insertion of the lunar between the two principal bones of the lower row is a feature common to all Paridigitata; only in *Hippopotamus* (Plate XXXVII. fig. 1, *l*) the beak, owing to the squareness of all the bones, is much blunted; but it is very well seen in *Anoplotherium*, *Xiphodon* (Plate XXXVII. figs. 2 & 3, *l*), the Suina and Ruminantia. The beak is limited on both sides by two oblique facets, one radial for the os magnum, the other ulnar for the unciforme; a ridge running from the anterior point of the beak through the whole antero-posterior depth of the bone separates the two facets from one another. On the anterior half of the distal surface of the lunar, the ulnar facet for the unciforme is larger than the radial or os-magnum facet; but on the posterior half this relation of the two facets is inverse: this disposition is obviously an adaptation for the better interlocking of the carpals.

The posterior termination of the lunar is very like that of the lunar of the Suidæ: the lateral facets for the two adjoining bones show nothing particular; only the upper radial facet covers the whole upper and inner margin of the lunar, while the ulnar is only developed on the fore part, the ulnar side not touching the pyramidal in its middle and posterior part. I have, from Hempstead, a lunar bone much larger than the one described and figured by me in the restoration of the carpus (Plate XXXVIII. fig. 5); it may have belonged to the largest species, called *Hyopotamus bovinus*, although it looks too large for it; there is no difference in shape whatever.

Dimensions.

	Hyopotamus.	
	Hempstead.	Hempstead.
Height, anterior	19, 22	27½
Breadth, anterior	14, 17	20
Depth, antero-posterior	22, 22	28½

The unique specimen of the lunar I possess from Puy, although agreeing entirely with that from Hempstead, is somewhat too much crushed to admit of accurate measurements.

The *pyramidal* (Plate XXXVIII. fig. 5, *p*) has the shape which is so characteristic of it in all Paridigitata. We may remark, in reference to this bone, that it is the least changeable of all the carpal bones, its shape being very similar, even in animals of widely different families and even orders. For instance, it is very like in both Paridigitata and Imparidigitata; and a pyramidal of Rhinoceros is hardly to be distinguished from that of a Hippopotamus. We may suppose that, as this bone has a very similar function to perform in all Ungulata, it did not change its shape, while the other bones, more directly acted upon by the different condition of life, did.

The pyramidal of *Hyopotamus* presents therefore a certain likeness to that of an *Anoplotherium*, and also to that of a common hog; the chief distinction lies in the fact that all its edges are much sharper, and not so much blunted as in Suidæ; this applies particularly to the ridge separating the facet of the ulna from the facet for the pisiforme (Plate XXXVIII. fig. 5, *p*).

The distal surface, adapted to the outer proximal facet of the unciform, is shaped very much as in all other Paridigitata.

I have this bone only from Puy.

Dimensions.

Height	18⅛
Greatest antero-posterior depth	18
Breadth	12

The *pisiform* is wanting; it is, however, not a very important bone, partaking more of the character of a sesamoid than of a true carpal.

The *second row of the carpus.*—I could not find the trapezium in any collection, although a facet on the radial side of the trapezoid and the second metacarpal clearly show that it was present. As the first digit is always abortive in all living and fossil Ungulata, the trapezium, which is the true carpal bone of this digit, has lost all its importance. However, it is to be seen in *Hippopotamus* and *Anoplotherium* (Blainv. Ost. *Anopl.* pl. iii.), where it articulates with the posterior face of the trapezoid, and assists in holding the second metacarpal in *Hippopotamus*, or the rudiment of the second in *Anoplotherium*. It is present in the Suidæ (Plate XXXVII. fig. 4, *tz*); and I found it also in *Phacochœrus* and *Babirussa*; it seems to hang only on the back part of the trapezoid (*t*), without touching the second metacarpal. The trapezium is very small in *Dicotyles* (Plate XXXVII. fig. 5, *tz*), and is entirely lost in ruminants, not being even present as a distinct point of ossification in the trapezoido-magnum cartilage. It is worthy of notice that, though the metatarsus in all Ungulata is always more reduced than the metacarpus, still the homologue of the trapezium (the first cuneiform) is often found in the pes when no trace of its homologue exists in the manus. So, for instance, in the Horse (coalesced with the second cuneiform) and most, if not all, Ruminants, in which the first cuneiform is present, while the trapezium is lost.

It is difficult to say if it existed in the *Diplopus*, seeing the reduction of its metacarpals to two; but as it exists in *Anoplotherium* there is no reason why it should be lost in the two-toed *Diplopus*.

The *trapezoid* (Plate XXXVIII. fig. 5, *t*).—I have this bone from Puy, belonging to *Hyopotamus* or the four-toed form. In considering only the shape of this trapezoid, without heeding the size, it is almost identical with the trapezoid of *Hippopotamus*; only its upper or proximal surface is more convex. The distal surface is deeper than it is broad, slightly concave, and fits exactly the proximal surface of the second metacarpal (Plate XXXVIII. fig. 5, *t*). On its radial side is seen a well-developed articular facet for the trapezium. If we compare this trapezoid with that of a pig (Plate XXXVII. fig. 4, *t*), we shall find a great difference, especially in the distal surface. In *Hyopotamus*, as well as in *Hippopotamus*, the trapezoid is destined to support only its typical metacarpal (the second), while in the Suidæ, owing to the larger development of the middle, and consequent reduction of the lateral metacarpals, one half of the distal surface of the trapezoid is taken by the third metacarpal, and only the remaining half supports the second (Plate XXXVII. fig. 4, *t*). In consequence of this, the distal surface of this bone in the true Suidæ, instead of being flat, is spear-shaped, with a sharp edge running through its whole antero-posterior depth. In *Dicotyles* (Plate XXXVII. fig. 5, *t*), where the reduction of the lateral metacarpals has gone still further, the distal surface of the trapezoid, being wholly taken by the third metacarpal, has resumed its flat form, thus resembling more the trapezoid the *Hyopotamus* than that of the pig. But notwithstanding this similarity, the part played by this bone in *Dicotyles* and *Hyopotamus* is wholly different; and while in the first it has no connexion with the second metacarpal, in the last it is entirely connected with it, and gives no facet to the third metacarpal.

Dimensions.

Height	10½
Breadth, inf.	8
Antero-posterior depth . . .	15

Unfortunately the *os magnum* is wanting in all the collections I have visited; but the interval included between the surrounding bones gives an idea of its shape, which certainly must have approached that of *Anoplotherium*. I pass on to the most important of the bones of the second row—the *unciform*.

Happily we are very well off as to this bone, there being some excellently preserved specimens from Puy. The shape of this bone and its connexion with the adjoining parts present considerable interest.

The *unciform* of *Hyopotamus* (Plate XXXVIII. fig. 5 *u*, fig. 7) presents some likeness to the same bone of *Anoplotherium* and also of *Sus*; but nevertheless its differences from both, especially the last, are numerous. Comparing the front view of fig. 5 and the view of the distal surface (fig. 7) with the corresponding aspects of the unciform of *Anoplotherium* in CUVIER (plate 102, fig. ii. A 2 & 3), we shall see that they present many features in common in both genera; I shall add that in CUVIER's figure (A 3), the letter *k* corresponds with our III., the letter *h* with our IV., and the letter *i* with our V.*

Looking at the bone from above or in front (Plate XXXVIII. fig. 5, *u*), we see that its radial facet articulates with the outer face of the lunar bone, while its ulnar facet is occupied by the pyramidal. The facet for the pyramidal is larger than that for the lunar, both in *Hyopotamus* and *Anoplotherium* (Plate XXXVIII. fig. 5, *u*, and Plate XXXVII. fig. 2, *u*), while it is just the reverse in *Sus*, where the lunar facet of the unciform is much larger than the pyramidal facet. Both facets are divided by a pretty prominent ridge. The whole bone is relatively higher than in *Anoplotherium*, in correspondence with the lighter and more elegant stature of the *Hyopotamus*.

The distal articular surface is shown in Plate XXXVIII. fig. 7, and may be compared with the same aspect of the unciform of *Anoplotherium* (CUV. pl. 102. fig. ii. A 3). We find on our bone the same facets; only their relative development is different. III. is the radial inferior facet, giving articulation to the prolonged beak of the third metacarpal (*k* in CUVIER); IV. is the middle, principal, or central facet, articulating with the fourth metacarpal (*h* in CUVIER); outside from it is seen another smaller, facet (V.) for the lateral or fifth digit (CUV. *i*)†; and we see just the same in the Suidæ, which have a complete fifth digit, and in *Anoplotherium*, where there is only a rudiment of it. In *Hyopotamus* and *Hippopotamus* (Plate XXXVII. fig. 1), however, owing to the greater development of the fifth metacarpal, this facet is not pressed so much backwards and upwards as in the pigs; in the living *Hippopotamus* it is entirely on the same level with the facet for the fourth metacarpal (Plate XXXVII. fig. 1, *u*).

---

* In CUVIER the bone is turned in an opposite direction, though it is from the same side, the left.

† CUVIER (Oss. Foss. 4th ed. vol. v. p. 425), describing this facet *i* as supporting the rudiment of the fifth toe, adds, "On n'en trouve l'analogue ni dans le bœuf, ni dans le cochon, ni dans le Tapir, &c." It is certainly not found in *Bos*, as the Ox has no rudiment of the fifth toe; but it is always to be found in the Suidæ as well as in the Tapir, both these having a completely developed fifth toe, which is articulated to the homologue of this facet. In all Mammalia, without exception, the unciform supports the fourth and fifth metacarpals; therefore in all mammals both these facets are homologous, whether they support completely developed toes or only rudiments of such, as in *Anoplotherium*.

In examining the radial side of the unciform of *Hyopotamus* we shall see that the upper lunar facet of this bone nearly meets the lower facet (Plate XXXVIII. fig. 7), the two being separated merely by a ridge*, while in *Anoplotherium* (Plate XXXVII. fig. 2, *u*, and Cuv. plate 102. fig. ii. A 5 *m*) these two facets are separated by a vertical facet, which articulates with the neighbouring os magnum. In the *Suidæ* this facet is exceedingly developed, and the homologue of the lower facet III. (Plate XXXVII. fig. 7) is confluent with it in such a way that both together (*k*+*m*, Cuvier, Oss. Foss. pl. 102. fig. ii. A 5) form the radial high and perpendicular border of the pig's unciform; at the upper part of this perpendicular border abuts the os magnum, at the lower the beak-like projection of the third metacarpal; this last projection, therefore, is more horizontal in Suidæ, and not so oblique as in *Anoplotherium* and *Hyopotamus*. The posterior projection of the unciforme is tolerably broad and well developed, as is seen in Plate XXXVIII. fig. 7.

Dimensions.

	Unciform from Puy.	Unciform from Hempstead (fig. 9).
Transverse breadth	22	17
Depth, antero-posterior . . .	22½	17
Height	17	12

I had already completed this description when I received unexpectedly, through the kindness of Mr. Davies, sen., of the British Museum, two carpal bones from the Museum in Cambridge. On examination both proved to be unciforms. One of them (Plate XXXVIII. fig. 9 & 9′) corresponded very closely to our unciform from Puy, being, however, much smaller; it may have belonged to some of the smaller *Hyopotami*, whose metacarpals, corresponding entirely in shape with those from Puy, are often found at Hempstead. This small unciform is figured in Plate XXXVIII. fig. 9, front view, 9′ the distal surface; it is from the left side, like the corresponding one (figs. 5 & 7) from Puy. Its distal articular surface (Plate XXXVIII. fig. 9′) has three facets—one for the beak-like projection of the third metacarpal, a central one for the fourth metacarpal, and an outer (v.) for the metacarpal of the small or fifth digit. The posterior part of this small unciform is drawn out into a tolerably broad backward projection.

The second of the two unciforms received from Cambridge was found at Hordwell; it proved a most valuable addition to my materials, as, after a careful study, I arrived at the conclusion that it undoubtedly belonged to the large didactyle form referred by me to the genus *Diplopus* with the specific name *Aymardi*. Figs. 8 & 8′, Plate XXXVIII. give a front and a distal view of this interesting bone. Comparing it with the same bone from Puy, or the small one from Hempstead, we are at once struck by their difference. The front view, in consequence of the large development of the inferior radial angle, presents a much squarer outline; the inner vertical wall of the bone has become much higher, reminding one precisely of what is seen in *Sus*, and even more so in *Hyomoschus*. The distal surface (Plate XXXVIII. fig. 8′) is also very different. The facet for the third metacarpal, instead of being oblique as in the bone figs. 5 & 7, *u*, Plate XXXVIII. (where it forms an oblique truncature of the inferior radial angle on the unciform), has gone over to the inner or radial vertical wall of the bone, forming a facet homologous to that of the Hog, composed of the facets $k+m$ of the *Anoplotherium* (Cuvier, pl. 102. fig. ii. A 5). In consequence of this the beak-like projection of the third metacarpal in the two-toed form is more horizontal (Plate XXXVIII. fig. 6, iii.) than in the four-toed form (fig. 5, iii.), approaching what is presented by the *Suidæ*. The distal surface (fig. 8′) shows no trace of the outer facet for the fifth metacarpal, and is entirely taken up by the greatly enlarged facet of the fourth; and the margin of this facet is so sharp that it is evident that the rudiment of the fifth metacarpal (whose existence is proved by a facet on the outer side of the fourth metacarpal) did not touch the unciform, confining itself to the lateral upper facet of the fourth metacarpal.

---

* This makes the *Hyopotamus* unciform look exceedingly like that of a *Palæotherium crassum*; but this similarity is only superficial, as the distal surface and the posterior beak are very different from what we see in Palæotheridæ.

The *posterior* projection of the unciform (fig. 8′) is very much broadened, so that the whole distal surface acquires a somewhat square outline; but what is more interesting, the inner or radial inferior margin of this projection has a large round facet* by which it articulated posteriorly with the os magnum. We never meet with such an enlargement of the posterior par tof the unciform in the true *Suidæ*, as in these the posterior and inferior parts of the unciform and magnum do not articulate together. Such an enlargement, however, is seen in *Dicotyles*, where the unciform sometimes touches the magnum, while in *Hyomoschus* we see, on the inner side of the same posterior enlargement of the unciform, a round facet for the magnum; this facet is also very characteristic of the unciform of all true ruminants. The reason of this closer articulation between the magnum and unciform seems to lie in the reduction of the lateral metacarpals, which caused the carpal bones to concentrate more towards the central part of the carpus.

The proximal, or upper, surface of this unciform is also much broader and flatter than in the four-toed form, both facets for the lunar and pyramidal being more on one plane. These two facets are very nearly equal in size, not as in the Pig, where the lunar facet is much longer and broader than the facet for the pyramidal.

Dimensions.

	Unciform of *Diplopus*, from Hordwell.
Transverse breadth	$21\frac{1}{2}$
Antero-posterior depth	21
Height	19

Tarsus of Diplopus *and* Hyopotamus.

The general structure of the tarsus in the Hyopotamidæ is quite conformable to the typical structure shown by all Paridigitata; and, in considering the shape of each of its constituent bones, I shall point out the features in which it resembles, or differs from, the other representatives of the same order. Fortunately the bones of the tarsus are much more numerous than the carpal bones both at Puy and in England; and I have been enabled to restore it completely, with the exception of the first cuneiform, which is wanting.

---

* This facet is seen in fig. 8′ from below, as a projection of the posterior and inner margin of the bone.

Calcaneum (Plate XXXV. fig. 4, Plate XXXVII. fig. 21, *c*).—This bone presents a remarkably uniform shape through the whole range of Paridigitata; in *Hyopotamus* (Plate XXXVII. fig. 21, *c*) and *Diplopus* (Plate XXXV. fig. 4) it is very similar to the calcaneum of a pig. Owing to this uniformity of the calcaneum in the Paridigitata, we must extend our comparison to the other series, or Imparidigitata, if we intend to find out what are really the characteristic and essential features of a Paridigitate calcaneum.

The general shape of the calcaneum in the entire order of Ungulata is, on a cursory glance, very similar; indeed, to find the typical differences we must enter into a deeper analysis of the bone in question. If we put before us some calcanea belonging to animals of the Imparidigitate series, for instance that of a *Palæotherium*, Tapir, Rhinoceros, or Horse, and try to compare them with those figured in our plates, or, still better, with the calcaneum of a Pig *in naturâ*, we shall immediately see that in the first* the upper and outer edge of the calcaneum, where it bends down to enlarge into the *sustentaculum*, forms a large articular projection (fig. 4′, *e*), which enters below and behind the external pulley of the astralagus; to the inner side of this articular facet we have the *sulcus sustentaculi* (fig. 4′, *s*), and, on the other side of this sulcus, another large articular oblong internal facet for the astragalus (fig. 4′, *i*). In correspondence with this, the posterior part of the astragalus of all Imparidigitata presents two large principal facets for the calcaneum—an outer facet, under the outer pulley, and an inner oblong facet.

Looking now, with a view to a strict comparison, at the same upper edge of the calcaneum of a Paridigitate (Plate XXXV. fig. 4; Plate XXXVII. fig. 21), we see that, at the point where the anterior edge bends down into the *sustentaculum*, it is divided into two parts by the *sulcus sustentaculi*; the external part, being the direct prolongation of the anterior edge, forms a prominent articular facet for the fibula (Plate XXXV. fig. 4, *ff*); the inner part, being situated on the sustentaculum proper, gives a large single facet for the posterior part of the astragalus (*as*). Considering these two facets in reference to the sulcus sustentaculi, I thought that the outer astragalean facet of the calcaneum of the Imparidigitata (*e*, fig. 4′) ought to be homologized with the fibular facet of the calcaneum of the Paridigitata (fig. 4, *ff*), and the inner oblong astragalean facet of the calcaneum of Imparidigitata (*i*, fig. 4′) with the single astragalean facet on the sustentaculum of Paridigitata. Comparing *in naturâ* the calcaneum of a pig and a horse, this is the view which seems most natural: it looks quite as if the outer astragalean facet of the Horse's calcaneum, instead of being buried under the outer pulley of the astragalus, had got to the outside of it, and were articulated with the fibula. Such a view of this homology is still more strengthened if we consider the relation between the two bones in *Anoplotherium* (Plate XXXVII. fig. 11, and De Blainville, *Anopl.* iv.); in this animal the fibular facet of the calcaneum is still covered by a process of the astragalus; it seems as if it were just one of the stages of the progressive march of the fibular process from under the outer pulley to the outer side of the astragalus.

---

* To make my comparisons better understood I figure the front view of an Imparidigitate calcaneum (Plate XXXV. fig. 4′); it belongs to *Anchitherium*. The calcaneum (Plate XXXV. fig. 4′) is a left one, while the two calcanea (Plate XXXV. fig. 4 and Plate XXXVII. fig. 21) are right.

As all *Imparidigitata* have *two* chief astragalean facets on their calcaneum (Plate XXXV. fig. 4′, *e* and *i*), and no facet for the fibula, and as all *Paridigitata* having a fibular facet on their calcaneum (fig. 4, *ff*) have only *one* chief astragalean facet, it seems natural to say that the second (external) astragalean facet of the Imparidigitate calcaneum is not lost in the Paridigitata, but has been made use of for the formation of the fibular facet. But there seems to exist an objection to this view; and it is furnished by the *Macrauchenia*, the strange South-American form, which seems really to be a sort of Imparidigitate Camel. The calcaneum of *Macrauchenia*, however, is *not known*; but the astragalus figured by Professor Owen in the 'Zoology of the Voyage of the Beagle' (plate xiv. fig. 4) clearly shows that there were two principal facets for the calcaneum, as in all typical Imparidigitata. Now the fibula has also on its distal extremity an articular facet for the calcaneum*; and this facet presupposes unerringly a similar fibular process on the calcaneum, as it exists in the Paridigitata. If this should be really the case, then the existence of two astragalean facets and a third fibular one will perhaps invalidate the view as to the homology explained above, and it would in this case stand thus:—that the single large astragalean facet in the calcaneum of the Paridigitata is homologous to *both* facets of the Imparidigitata ($e+i$, fig. 4′), the fibular facet of the former being a new superadded character, not found in any of our living or fossil Imparidigitata, but exhibited by the South-American *Macrauchenia*. So that, even with the large material in our hands we cannot quite certainly determine the homology of different parts of such an important bone as the calcaneum in both the chief series of Ungulata; and as we have no forms linking these two typically different calcanea together, this is one proof more of the very ancient separation of this order into its two principal groups.

The calcaneum of *Hyopotamus* (figured in $\frac{1}{2}$ nat. size, Plate XXXVIII. fig. 21) and of *Diplopus Aymardi* (Plate XXXV. fig. 4, nat. size) resembles very much that of a pig, with some slight differences. The sulcus which divides the fibular facet (*ff*) from the astragalean is very deep; this last facet has a slight angular rising or ridge nearer to its inner border, which fits into a corresponding slight depression in the posterior (calcaneal) surface of the astragalus; besides, as in all Ungulata, there is, at the inferior and inner border of the processus anterior, a smooth and large surface (Plate XXXV. fig. 4, *a s*) by means of which the inner wall of the calcaneum fits to the outer border of the inferior pulley of the astragalus. The fibular process (*ff*) is not so high, but much deeper antero-posteriorly than in the Suina; and we have seen that the distal extremity of the fibula is also extended in the same direction. The inner surface of the fibular process is very smooth, without the large prominence we see in pigs, where it enters deeply into the external wall of the astragalus. The inferior surface of the processus anterior is occupied by one tolerably broad facet for the cuboid (Plate XXXV. fig. 4, *cb*).

---

* Voyage of the Beagle, p. 51.

On the posterior surface of the thickened back end is seen a groove for the tendon of the musculus plantaris, which, as in all Ungulata, was certainly developed as a flexor digitorum; this groove is shallower than in the Suina.

Dimensions of Calcaneum.

	Hyopotamus, from Puy.	*Diplopus*, from Hordwell (Plate XXXV. fig. 4).
Length	95	96
Height at the fibular facet	37	47
Length of the processus anterior	34	40
Greatest breadth	22	23½

The *astragalus* (Plate XXXVII. fig. 21).—This is an extremely characteristic bone for determining the natural affinitiesof Ungulata; in *Diplopus* it is very nearly like as in *Hyopotamus*, and conforms to the general shape of this bone through the whole range of Paridigitata. It has a double pulley—a proximal one, fitting the distal ends of the tibia and fibula, and a distal pulley fitting the navicular and cuboid. In all Imparidigitata the astragalus has only one pulley, on its upper or proximal end, while the lower or distal is flattened, though articulating with the same two bones. (In *Macrauchenia* and in the Horse, the distal surface of the astragalus articulates only with the navicular bone.) This character of the astragalus is one of the best by which to distinguish at a glance the two series of Ungulata; and we know of no living or fossil animal which presents an astragalus linking these two divisions together. True, in the astragalus of *Hippopotamus* (Plate XXXVII. fig. 9, *a*), owing to the broadness and thickness of all the tarsal bones, the inferior pulley is so exceedingly low that it reminds one of the same distal surface of the astragalus in *Rhinoceros* (see De Blainville's plates); but this likeness seems to be only an analogical one, both animals having heavy tarsal bones adapted very nearly to the same function.

Although extremely like in general shape to the astragalus of a pig, that of the *Hyopotamus* is proportionately much higher, the distal and proximal pulleys being divided by a larger interval than in the Suidæ. That part of the distal pulley which fits the cuboid is perhaps produced a little more downwards than in the Suina, though the difference is very slight. In comparing the large astragali of the didactyle *Diplopus* with the smaller ones of *Hyopotamus*, we find very few differences indeed; but it may be mentioned that the proximal pulley of the two-toed form is relatively a little higher and enters more deeply into the distal end of the tibia (Plate XXXVI. fig. 7), which may be due to the greater narrowness of the reduced foot, requiring a more close articulation with the tibia.

Dimensions.

	Hyopotamus.		*Diplopus Aymardi.*
	Puy.	Hempstead.	Hordwell.
Length, tibial side	40 , 47	44, 43, 40	52
Length, fibular side	44½, 52	50, 50, 45	55½
Anterior breadth in the middle	21 , 29	25, 24, 23	28½
Transverse breadth, proximal pulley	23½, 27	26, 26, 23½	26½
Transverse breadth, distal pulley	24½, 30	28, 28	29

The *cuboid* (Plate XXXVIII. figs. 1, 3, 10, 11).—I have examined numerous and well-preserved specimens of this bone from Puy, Hempstead, and Hordwell; the cuboids from Puy and Hempstead (figs. 1, 10) clearly indicate the four-toed form called *Hyopotamus*, while the bones from Hordwell (figs. 3, 11) belonging to the genus called by me *Diplopus*, indicate, in the most unmistakable manner, that in this last animal the foot was didactyle, as the inferior surface of the cuboid shows no trace of a facet for a fifth digit as in *Hyopotamus*.

As the cuboid is one of the most important bones of the tarsus, I will give a detailed description of it, with as many figures as I can afford; but should the reader take a cuboid of a hog *in naturâ*, then many points that are difficult to explain by words will at once be plain to him.

I will begin, as I have nearly always done, with the description of the cuboid of *Hyopotamus* (Plate XXXVIII. figs. 1, 10), and afterwards compare it with that of the *Diplopus* (figs. 3, 11). As in all Paridigitata, which have the navicular and cuboid distinct, the front face of the cuboid of *Hyopotamus* is cut out *en équerre* (Cuv.); this is brought about by the circumstance that the cuboid articulates with two bones of the first row of the tarsus, the calcaneum and astragalus; and the facets for these two bones lie in different levels, the rounded crescentic facet for the outer half of the distal pulley of the astragalus rising in front, while the facet for the processus anterior calcanei presents a flat surface sloping forwards, as is plainly to be seen in the figures (fig. 1 *cl* and *as*). *The upper* or *proximal* surface of the cuboid is occupied entirely by these two facets, one internal, shaped like a concave crescent for the astragalus, the other external, like a convex sloping surface for the calcaneum. The proximal surface of a hog's cuboid shows the same facets; only the external one is often cut transversely in two by a rough deep notch for the passage of vessels and ligaments: this division of the astragalean facet of the cuboid is nearly constant in the Hog and *Dicotyles*, though I did not find it in *Phacochœrus* and *Babirussa*. The relations between the transverse breadth of the two proximal facets vary in different genera. In *Anoplotherium*, the calcaneal facet is much broader than the astragalean (Plate XXXVII. fig. 11); but in *Hippopotamus* and *Hyopotamus* the relation is reversed, while in most Suidæ both facets are very nearly of equal breadth.

The *internal wall* of the cuboid shows on its upper margin a small facet for the neighbouring navicular, and a little lower a very small rising which corresponds to the nterval between the distal surface of the navicular and proximal of the great or third cuneiform; the rising was very slight on our specimen, and is only imperfectly seen in the drawing. On the posterior part of the inner wall we see two facets divided by a groove for the external and posterior part of the navicular (in the Hog these *two* facets have coalesced into an elongated *single* facet on the posterior border of the inner wall of the cuboid). This posterior margin of the internal wall shows in *Hyopotamus* a considerable bulging inwards, into the middle of the tarsus (seen in Plate XXXVIII. fig. 10), which makes this cuboid much broader than the corresponding bone of the *Diplopus* (fig. 11), where this bulging is much less, nearly identical with that of a hog's cuboid.

The *outer surface* of the cuboid is rounded. If we look at the external surface of the cuboid of a hog we shall see a deep sulcus for the peronæus tendon situated between the posterior prolongation of the cuboid and the distal articular facet; this sulcus is absent in *Hyopotamus*, owing to the fact that the posterior part of the cuboid is not produced downwards, as we shall immediately see. The *posterior* surface of the cuboid is considerably broader than the anterior, as is to be seen in fig. 10, while in *Diplopus* (fig. 11), and especially in the Hog, the converse is the case. Besides, looking at the cuboid from the posterior aspect, we perceive a very broad and rough transverse ridge for muscular and ligamentous attachment, running through the whole breadth of the bone as it is seen in fig. 10 from below. The *Anoplotherium* and the *Hippopotamus* have nearly the same transverse ridge on the back part of the cuboid; only it descends lower down, while in *Hyopotamus* this ridge does not reach the level of the distal articular surface of the cuboid, which is the lowest point of the bone; we shall by-and-by indicate the difference presented in this respect by the cuboid of *Diplopus*.

The *distal* surface (Plate XXXVIII. fig. 10) is the most important, as it presents the articular facets for the two outer metatarsals. Not only in Ungulates but in *all* recent and fossil Mammalia the cuboid of the tarsus, as well as its homologue (the unciform) in the carpus, gives an attachment to the two outer metatarsals and metacarpals of the foot (the fourth and fifth) if they are not entirely reduced. In looking at the distal surface of the cuboid in *Hippopotamus*, we shall perceive a large central facet for the fourth metatarsal, and outwards from this another good-sized facet for the well-developed fifth metatarsal. In the common Hog, nearly the whole distal surface of the cuboid is taken up by the much developed fourth metatarsal; but still there exists at the outer part of this large facet a smaller and oblique facet for the still functionally developed fifth digit. In *Dicotyles*, where the fifth digit is lost, or only a short rudimental metatarsal of it remains, the whole distal surface of the cuboid is taken up by the fourth metatarsal, the rudiment of the fifth being only attached to the outer side of the fourth metatarsal, without touching the cuboid (De Blainville, *Sus*, plate vii. *Dicot. labiatus*, lowest left figure). In the *Anoplotherium commune*, as well as in *A. tridactylum*, there is not the slightest trace of a facet for a rudimentary fifth digit; but in *Xiphodon*, which also has only two developed metatarsals, we have on the distal surface of the cuboid a large facet for the fourth metatarsal, and an outer small facet for the rudiment of the fifth, which certainly existed, as the outer border of the fourth metatarsal has also a small facet, to which this rudiment was attached (Cuvier does not mention this, as he treats both *Dichobune* and *Xiphodon* very briefly). This additional facet for the rudiment of the fifth metatarsal is to be seen in De Blainville (*Anopl.* plate v.); it certainly existed in *Dichobune* and *Cainotherium*, as both have a completely developed fifth digit in the *pes* and *manus*.

Now, looking at the distal surface of the cuboid of *Hyopotamus* (Plate XXXVIII. fig. 10), we clearly perceive two large articular facets (iv. & v.) nearly in the same mutual relation as in *Hippopotamus*; the two facets are numbered iv. and v. in correspondence with the metatarsals they support; and their outline corresponds very nearly with the proximal surfaces of these two metatarsals (Plate XXXVIII. fig. 1, iv., v.). The inner border of the facet iv. is convex, the outer (near the ridge that separates the two facets) concave; and corresponding to this the inner border of the fourth metatarsal is concave, and the outer convex, to fit the cuboid. The facet v. is a little convex and triangular; and the metatarsal v. is shaped in a corresponding manner.

Besides the cuboid figured from Puy, I had a smaller cuboid from Hempstead, with two facets on its distal surface for the fourth and fifth metatarsals, and another from the same locality much larger than the Puy specimen, but corresponding closely with it; unhappily this last large specimen is much rolled, and the articular facets are not quite distinct.

If we compare with the cuboid just described the same bone from a nearly complete foot found at Hordwell (Plate XXXVIII. figs. 3, 4, and, distal view, 11) belonging to the *Diplopus*, or the two-toed form of this family, we shall see important differences which must clear away any possible doubt as to the number of digits in the genus *Diplopus*. The front view of the cuboid, fig. 3, shows it to be a little narrower than the same bone in its smaller but four-toed congener; and this is especially the case if we compare the posterior parts of both bones, as seen in figs. 10 and 11. On the inner wall, the middle anterior rising which enters into the interval between the navicular and third cuneiform is more distinctly developed, as seen in fig. 3; the rising, with a facet for the distal surface of the navicular, on the posterior border of the cuboid, is not so thick and not produced so much inwards as in *Hyopotamus*, but repeats entirely the arrangement seen in the Hog.

The external surface is more hog-like in appearance, and differs from the same surface of *Hyopotamus* by the presence of a deep sulcus (fig. 11) between the distal articular facet and the posterior prolongation (fig. 11, *f.my*), which, in this genus, is produced much lower down than in *Hyopotamus*. Instead of the broad transverse ridge seen on the posterior surface of the cuboid in the *Hyopotamus* (fig. 10, *tr*), the cuboid of the two-toed *Diplopus* has this ridge prolonged downwards in a beak-like process quite of the same shape as in the common Hog (fig. 4, *b.cb*). This posterior beak descends lower down than the distal articular surface of the cuboid, and exhibits on its inner side an elongated facet (fig. 11, *f.my*) by which this beak articulates with a corresponding cuboid facet on the outer side of the posterior prolongation of the fourth metatarsal (fig. 4″, iv. *cb.f*). This articulation is observable, though imperfectly, in fig. 4, where the beak of the cuboid (*b.cb*) is seen descending on the other side of the fourth metatarsal. In my specimens of *Hyopotamus* from Puy the posterior prolongation of the fourth metatarsal is not well preserved (Plate XXXVIII. fig. 2′, IV.); but as there is no downward prolongation in the cuboid and no facet, the cuboid seems not to have articulated with this posterior prolongation of the fourth metatarsal, and it does not so articulate in *Anoplotherium* and *Hippopotamus*. In the Hog the relations are just the same as in the didactyle *Diplopus*; only this beak has on its outer side another small facet, for the posterior prolongation of the outer or *fifth* metatarsal—which is wanting in *Diplopus*, and, though present in *Hyopotamus*, has no such posterior prolongation as in the Hog. A glance at a hog's tarsus will make all this much clearer.

The *distal* surface of the cuboid in *Diplopus* (Plate XXXVIII. fig. 11) is entirely taken up by a single large facet for the fourth metatarsal, leaving no place at all for an additional digit as in fig. 10, though a rudiment of such fifth digit certainly existed, as is proved by a small facet on the outer border of the fourth metatarsal, to which this rudiment was undoubtedly attached, without ascending, however, so far as to touch the cuboid.

All these differences clearly indicate that the Hyopotamoid form to which this cuboid (fig. 11) belonged had no fifth metatarsal, but only a rudiment of it; we have seen the same thing in the manus, where the unciform, instead of supporting two toes, is shown by the distal articular facets to have supported only one (the fourth) while a rudiment of the fifth, indicated by an external facet of the upper border of the fourth metacarpal, did not reach the unciform and left no trace upon it.

Dimensions of the Cuboid.

	Hyopotamus, from Puy (Plate XXXVIII. figs. 1, 10).	*Hyopotamus*, from Hempstead.	*Diplopus*, from Hordwell (Plate XXXVIII. figs. 3, 11).
Height, anterior	26	19, 31	23
Breadth, upper part	21	17, 24	19
Breadth, inferior, on the distal surface	18	15, 21	16½
Antero-posterior depth	25	25, 28½	25

The *navicular* (Plate XXXVIII. figs. 1–4, *n*).—This bone is nearly identical in both genera, and has the same general shape as in all Paridigitata, in which the navicular is separate from the cuboid. The upper or proximal surface is entirely the same as in the Hog, except that the middle rising which fits into the groove of the distal pulley of the astragalus is more rounded. The inner (fibular) surface has, on the anterior and posterior part, facets corresponding with those already described on the tibial side of the cuboid. The posterior termination is rounded and only moderately produced downwards (as seen in figs. 2 and 4), without such large beak-like prolongation as is seen on the posterior side of the navicular of a hog (Plate XXXVII. fig. 12, *n*) or *Dicotyles* (fig. 13, *n*).

The *distal* surface is the most important one, as it supports the three cuneiform bones, which carry the digits. All the anterior part of the distal surface of the navicular is occupied by a broad facet for the great or third cuneiform, which supports the third metatarsal. I have not figured the distal extemity of the navicular; but, by looking at the distal surface of the *Anoplotherium* navicular (Plate XXXVII. fig. 17) or that of a hog, the reader may form a correct idea of it. This facet is much narrowed in its posterior part, and then expands slightly again, forming a small facet for the *second cuneiform*; behind this there is a slight sharp ridge, which is seen tolerably well in the side view, fig. 4, Plate XXXVIII., as well as on a navicular of the Hog (Plate XXXVII. figs. 12, 13, *n*); behind this ridge is the facet for the first cuneiform. This last facet is concave on some of the naviculars of *Hyopotamus*, and convex on the two others belonging undoubtedly to the two-toed *Diplopus*; whether the difference was constant I cannot tell without ampler materials. I find no essential differences in the shape of the navicular bone in the two genera; and my description, made from good specimens of the *Diplopus*, may apply to the *Hyopotamus* also; of this last I had only one, not quite perfect, specimen of navicular from Puy.

Navicular of the Tarsus.

	Hyopotamus. from Puy.	*Diplopus,* from Hordwell.
Anterior height	11	12½, 14
Breadth, proximal face	15½	15, 17
Depth, antero-posterior	24	26, 30
Breadth, distal surface	14	14½, 20

The *cuneiforms* (Plate XXXVIII. figs. 1–4, c^3).—These are small but very important bones, on account of their relation to the digits which they have to support. The second row of the tarsus, containing the three cuneiforms and the cuboid, exhibits very clearly the complete homology of the fore and hind limbs. As in the complete manus we have in the second row of the carpus three distinct bones (the trapezium, trapezoideum, and magnum), each supporting a separate toe, and one external bone, the unciforme, giving support to the two outer digits (the fourth and fifth), so in the pes we perceive also an entirely homologous set of three cuneiforms (first, second, and third), each supporting a separate toe, and one external bone, the cuboid, giving support to the two outer digits of the pes (the fourth and fifth). Where all the five digits are completely developed this rule admits of no exception whatever in the whole range of Mammalia; but where, as in Ungulata, the number of the digits becomes sometimes greatly reduced, the relation of the carpal and tarsal bones to the remaining digits is slightly changed, though all the three cuneiforms are still retained, and I know of no instance where one of them is wanting. This persistence of cuneiforms is a strange fact; for in the carpus, which is generally less reduced than the tarsus, the trapezium (homologue of the first cuneiform) is certainly lost in Horses and Ruminants, while its homologue in the tarsus is still retained in a recognizable state. These relations, slight as they may seem, are important; we must know all the details and the true homology of the smallest bones to establish clear lines of descent. I shall be obliged to discuss the question of the cuneiforms again when I come to describe the metatarsals, and will confine myself in this place to a general review of them in the Paridigitata, and a special description of these bones in *Hyopotamus* and *Diplopus*. As the *Hippopotamus* is the most complete of the living Paridigitata, we see in the side view of its tarsus (Plate XXXVII. fig. 10) all the three bones (c^1, c^2, c^3) fully developed; but as the first digit is aborted, its typical tarsal bone, the first cuneiform (c_1), gives additional support to the second digit. Each of the two inner digits (the third and second) are supported by a separate cuneiform. We see besides, in this side view of the tarsus, that the second digit (fig. 10, II.), besides its own tarsal bone (the second cuneiform), seeks additional support from the large third cuneiform: we shall discuss this relation when we come to the metatarsals; and I will merely observe here that it seems to be a very ancient one, which existed perhaps in the progenitor of the whole class of Mammalia. In the Hog (Plate XXXVII. fig. 12) we find the three cuneiforms quite distinct; but there is a great change in their relative position: instead of the third cuneiform giving additional support to the second digit, it is now not only entirely occupied by the enlarged third digit, but even the greater part of the *second cuneiform* leaves the reduced second digit to give additional support to the enlarged third.

The *first cuneiform* is also peculiar in the Hog; it is thrust like a wedge between the posterior beak-like prolongation of the navicular, the head of the second metatarsal, and a posterior process of the third metatarsal, to which it gives an articular facet. Remembering what we have said in reference to an analogous beak-like prolongation of the cuboid in hogs, and looking at a hog's tarsus *in naturâ*, we shall see that the wedge-shaped first cuneiform, together with the cuboid, press from within and without on the posterior processes of the third and fourth metatarsals, and make the two middle metatarsals act like a single undivided bone: this is moreover aided by a special provision in the articulation of the distal extremities of these metatarsals with the first phalanges; namely, the outer borders of the *combined* distal extremities of the two metatarsals are produced down less than the inner, so that the digits, being expanded in treading on the ground, tend to meet by their proximal ends and compress both metatarsals firmly together, thus materially aiding the compression of their upper extremities by the beak-like prolongation of the cuboid and the wedge-like first cuneiform. There is nothing of the sort in *Hippopotamus*; but the same provision existed in the two-toed *Diplopus*.

Dicotyles (Plate XXXVII. fig. 13) presents nearly the same relations; only the second cuneiform (c^2) has gone entirely over to the third digit; and after this there was no assignable reason why these *two* bones, giving support to a *single* metatarsal, should not coalesce: and this they have done in *Hyomoschus* and *Tragulus* (figs. 14 and 15, c^3, c^2), where the navicular has also coalesced with the two cuneiforms, the first cuneiform (c^1) remaining entirely distinct in both. In a Miocene ruminant from Auvergne, fig. 16 (*Amphitragulus* ?), with a rudimentary second metatarsal, we may also clearly perceive that the large cuneiform is formed by the coalescence of the second and third, while the first cuneiform remains distinct, giving support to the rudimentary metatarsal II. The same relation may be seen in our recent Ruminantia, whose large cuneiform bone is therefore to be taken as the homologue of the third and second, the first remaining distinct.

Having traced our three cuneiforms, even in the most reduced Paridigitata, it is natural to ask how the matter stands in *Anoplotherium*, the reputed prototype of every Paridigitate. In this respect the confusion is very great; and it originated with CUVIER. In his description of the Anoplotherian pes he says ('Oss. Foss.' 4th ed. p. 147, plate 128), that he found "le grand cunéiforme *C*" (which is our third cuneiform) and, besides, another bone (plate cxxviii. fig. 2, *h*), which he calls "osselet surnuméraire," and assumes to be a rudiment of the second digit, saying (p. 147) that it articulates to the facet *i* of the scaphoid, and the facet *k* of the third metatarsal. (This bone is, no doubt, our first cuneiform, Plate XXXVII. fig. 11, c_1.) If we look at the restoration of the pes of *Anoplotherium* in DE BLAINVILLE, and read his text, we shall see that he speaks of three cuneiforms, and even figures them (DE BLAINVILLE, 'Ostéogr.' *Anopl.* plate iv., side view of pes); *B* is the third cuneiform, *C* the second; and the bone lying backwards from it is certainly the first cuneiform. I take this restoration to be in the main right; only the second cuneiform, which is represented in the side view as articulated to the scaphoid, has, in his figure of the distal extremity of the scaphoid (a little below), no such facet on this bone, the facets figured being for the first and third cuneiform only. But if we read his text we shall find the confusion which is so characteristic of his palæontological writings. He says:—"Les os cunéiformes sont au nombre de trois: le *premier*, assez allongé . . . . collé contre le métatarse; le *second* presque de même forme, un peu moins reculé, articulé avec le scaphoïde d'une part et le métatarsien du medius de l'autre, et enfin le troisième . . . . articulé carrément avec le scaphoïde en haut et la métatarsien du medius en bas."—*Anopl.* p. 35.

So, in the interpretation of DE BLAINVILLE, the first cuneiform does not touch the scaphoid at all (in the description of the scaphoid, p. 35, he says:—"le scaphoïde a à son bord interne un tubercule ovale un peu saillant pour l'articulation du *second* cunéiforme, outre un beaucoup plus grand pour le troisième"), but is applied to the third metatarsal, the second cuneiform being, in his description, also articulated with the same metatarsal; and the third cuneiform is the chief support of the third digit. All the three cuneiforms, then, are said by DE BLAINVILLE to articulate with the third metatarsal; but I regret to say that this is entirely incorrect. I enter into such detailed descriptions only because such matters should be at once set right; the real state of things is this:—The *Anoplotherium* possessed all the three typical cuneiforms * in their typical relation; and, besides, a rudiment of the second digit pressed against the upper margin of the third digit. To prove this, I have figured the pes of the *Anoplotherium* from Vaucluse, where this rudimentary digit is completely developed (Plate XXXVII. fig. 11), we see in this foot the three typical cuneiforms nearly in the same relation as in *Hippopotamus*; the third cuneiform articulated to the third metatarsal, the second cuneiform to the metatarsal of the short second digit; the first cuneiform, seen behind, aids to support this short second digit. I have represented in Plate XXXVII. fig. 19 the distal surface of the navicular of this *Anoplotherium tridactylum*; and we distinctly see the three facets for the three cuneiforms, which all articulated with the navicular bone. Together with these navicular bones from the tridactyle form, we have from Vaucluse some naviculars of the didactyle species (fig. 18): the complete second digit is reduced in this species to a mere rudiment; and we see a corresponding diminution of the facet for the second cuneiform which supported this rudiment, the facet for the third remaining nearly of the same size. Now in the *Anoplotherium* from the Paris gypsum, as I see by a navicular in the British Museum (fig. 17), this facet for the second cuneiform is even smaller, but it exists still. As far as I can judge by a cast of another Anoplotherian pes in the Museum, the facet for the second cuneiform is absent from it; but still we see a trace where this very reduced second cuneiform leaned against the third, perhaps not touching the navicular; the posterior navicular facet for the first cuneiform remains very large. The reduction of metacarpal and metatarsal bones always precedes that of the carpals and tarsals; and when a rudiment of the former still lingers, we may be sure to find the corresponding tarsal or carpal; and so it is in *Anoplotherium*, which possessed besides its three typical cuneiforms a rudiment of the second metatarsal.

---

* Their relations to the metatarsals were entirely identical with what we see in *Hippopotamus*: the third cuneiform supported the third digit; the second cuneiform supported (the rudiment of) the second digit; and the first cuneiform was articulated to the navicular above the second cuneiform in front, and the rudiment of the second digit below.

Proceeding now to the *Hyopotamus*, we find that it, as well as the *Diplopus*, had three cuneiforms to its tarsus; but unfortunately the first is absent from all collections examined by me; the second is preserved, thanks to its tendency to coalesce with the third or great cuneiform. The shape of the third cuneiform is very like that of the same bone in the Hog or *Anoplotherium*; it is articulated to the third metatarsal below (Plate XXXVIII. figs. 1–4); and its tibial or inner border gives additional support to the second metatarsal *, as its homologue, the magnum, does in the carpus. The *second cuneiform* is a small nearly cubic bone. I have never seen it separately, as it is always lost owing to its small size; but it is represented in fig. 2, having coalesced with the third cuneiform, and giving support to the second metatarsal. The third cuneiform of *Diplopus*, figured in the nearly complete tarsus (Plate XXXVIII. figs. 3 and 4), is in all respects similar to that of *Hyopotamus*; only, as seen in fig. 4, it did not give any attachment to the rudiment of the second metatarsal, as it does to the complete second metatarsal in *Hyopotamus*; nay, more, the tibial upper margin of the third metatarsal in this specimen has a very slight truncature or oblique facet, by means of which this third metatarsal touched the second cuneiform, a deviation from typical relations which is enormously developed in the Hog (Plate XXXVII. fig. 12, III. c_2); the proximal surface of the rudimental second metatarsal (Plate XXXVIII. fig. 4, II. r) is therefore a little lowered in this specimen, to allow the second cuneiform to touch the third metatarsal. On the contrary, in two other specimens not figured, the relations remain true to type, and it is the third cuneiform which gives a small facet to the rudiment of the second metatarsal.

---

* In fig. 2, Plate XXXVIII., the second metatarsal rises a little higher than the third, and touches the internal side of the third cuneiform. The same is to be seen in *Hippopotamus* (Plate XXXVII. fig. 10) and *Anthracotherium*. This relation is essential in an unreduced tarsus.

I have found, moreover, in the British Museum a specimen of the *Diplopus* from Hordwell in which the two cuneiforms (2+3) had coalesced in the same manner as the two cuneiforms of the *Hyopotamus* of fig. 2. The distal surface of these two coalesced cuneiforms is given in outline below fig. 4, Plate XXXVIII., to show its correspondence with the proximal surface of the third metatarsal; and it answers so exactly to the third metatarsal with the coalesced rudiment of the second, figured in fig. 4″, that one may think they belonged to the same individual [my coalesced cuneiforms, however, are from the other (right) side]; and the correspondence to the figured foot is so exact that even the *second* cuneiform presents a small facet (the shaded bit of the outline below fig. 4) to the third metatarsal. So that in this specimen the overdeveloped third metatarsal seeks additional support from an adjoining tarsal bone. In the Suina it accomplished the passage long before the loss of the second lateral digit, as seen in figs. 12 and 13, Plate XXXVII.

A similar case is described in my Memoir on *Anchitherium* *: here also the third cuneiform became, in the same way, confluent with the second, to pave the way for the overdeveloped third (and single) metatarsal to enlarge and usurp the second cuneiform, which bone typically belongs to the second digit.

The first cuneiform is absent; and, judging from the absence of a facet for this bone on the posterior prolongation of the third metatarsal in *Hyopotamus* (Plate XXXVIII. fig. 2), we may infer that it did not articulate with it; but in *Diplopus* such facet on the posterior prolongation of the third metatarsal is clearly seen (fig. 4″, fc_1), and furnishes a conclusive proof that the first cuneiform was articulated to it in the same manner as in the Hog. Above, it was articulated to the somewhat convex posterior facet of the navicular (seen in figs. 4 and 2, Plate XXXVIII.), then touched the back part of the small second cuneiform, and, being prolonged lower down, leaned against the posterior part of the second metatarsal (as proved by a facet on this bone) in *Hyopotamus* (fig. 2), or against the rudiment of this second metatarsal in *Diplopus*, as seen in fig. 4, Plate XXXVIII. In this latter the first cuneiform was probably thrust like a wedge between this rudiment and the posterior prolongation of the third metatarsal, in the same way as it is to be seen on a hog's tarsus (Plate XXXVII. fig. 12).

Metacarpus and metatarsus.—When I began to study the structure of the anterior and posterior extremities of the Anthracotheridæ and Hyopotamidæ in the collections of the Museums of Lausanne and Puy I had no doubt whatever that the genus imperfectly known under the names of *Hyopotamus* and *Bothriodon* had four completely developed digits on both extremities; and all I had seen in the collections of Puy confirmed this inference; besides, as I could not find any difference in the dental or osteological characters between these two supposed genera, I was obliged to unite them, giving priority to Professor OWEN'S denomination. But, whilst studying the fossil remains from Hordwell and Hempstead in the collection of the British Museum, I gradually acquired the conviction that we have, in the English deposits, two very different forms of the same natural family, which, though entirely similar in most of their osteological characters presented a wide difference in the composition of their manus and pes, a difference somewhat similar to the difference we see in our own times between *Hyomoschus* and the true Ruminants. One form had clearly four completely developed digits, while the other had only two. At first I struggled against this conclusion, as the fact seemed too singular, considering the similarity of all the other bones of the skeleton; but by-and-by, as I got more materials, all doubt cleared away; and having once ascertained this point, I felt obliged to subdivide the family of Hyopotamidæ into two groups or genera, *Diplopus* and *Hyopotamus*, whose chief distinction lay in the number of digits. It is more than probable that each group or genus was represented by several species, though this specific distinction is very difficult to establish. But I shall return to this question at the end of my memoir; at present I proceed with the description of the bones forming the metacarpus and metatarsus in both genera. As I have generally done, I commence with the tetradactyle form, or the *Hyopotamus*, and shall proceed afterwards to the didactyle, or *Diplopus*.

---

* Mémoires de l'Académie de St. Pétersbourg, 1873.

Before, however, proceeding with the Hyopotamidæ, it seems necessary to cast a glance at the composition of the manus and pes in all Paridigitata, living and fossil, as such a general review will throw more light on the importance and value of the distinctions found in our fossil Hyopotamidæ than a tedious and minute description of their bones could do. Studying in detail the structure of the extremities of the living and extinct Ungulata Paridigitata, and especially their metacarpals and metatarsals, we meet everywhere, through all the great diversity of their forms, such striking similarity in all the smallest details, such adaptation of one typical structure to widely different conditions, that there seems to be no possibility of explaining it otherwise than by a common descent (with modification and adaptation) from some single ancient form which presented the arrangement we call typical for the whole of the Paridigitata. Looking upon the whole community of Paridigitata as modified descendants of one ancestral form, the theory of evolution says that each form must have inherited the typical structure of the common ancestor, modifying it in each particular case to the condition of its own life; and though, after the lapse of a great period of time, the diversity acquired by different forms would be prodigious, still every member of the cycle, even at the furthest points of descending lines radiating from the common ancestor, would by every single bone testify its relation to this common ancestor. And such is really the case with our recent Paridigitata. If the *Hippopotamus* and *Phacochœrus*, *Tragulus* and *Antilope*, seem wonderfully different, as being on the furthest points of the radiating lines, still they have every one of them strikingly similar typical characters inherited from the ancestral form which was the common progenitor of them all.

The chief and most obvious characters of a Paridigitate foot are to be seen in the shape and connexions of its two middle fingers; therefore I will commence with these, and state some general features common to all Paridigitata, living or fossil, without exception.

While, in the Imparidigitata, the axis in relation to which the whole foot is shaped is given by the middle or third digit, the axial line passing through its centre, we have in a Paridigitate foot always two middle digits (the third and fourth), which form the centre in relation to which the foot is arranged, the axial line passing in the interval between these two digits. These, then, may be taken as the principal digits of the manus and pes; they exhibit nearly always a certain mutual symmetry, and are interlocked at their upper extremities by a peculiar arrangement which is common to all fossil and living Paridigitata, as far as we know them now.

The mutual interlocking of the middle metacarpals is effected in this way. The fourth metacarpal has always, at its upper radial end, a process, or a smooth salient margin, uninterruptedly connected with its proximal articular surface: this process enters deeply into a corresponding excavation of the third metacarpal; and this excavation is overarched by a special ulnar process of the third metacarpal, which is inclined outwards, and abuts against the unciform. This is to be seen on all the figures of the carpus (Plates XXXVII. and XXXVIII.), and better still in De Blainville's Plates. In consequence of this projection of the third metacarpal the fourth stands always a little lower than its neighbour, and is supported entirely by the unciform, while the third is supported by the os magnum and partly by the unciform (Plate XXXVII. figs. 1, 2, 3, 20; Plate XXXVIII. figs. 5, 6), upon which it glides by means of its oblique outer and upper process.

The two middle metatarsals (the third and fourth) (Plate XXXVIII. figs. 1 & 3) show us something quite analogous; the fourth gives off from its upper tibial side a prominent process (not uninterruptedly connected with the proximal surface as on the fourth metacarpal), which enters into a deep corresponding cavity in the outer side of the third metatarsal. The fourth metatarsal is supported by the cuboid, the third by the third cuneiform.

Such is the general rule of the interlocking of the two middle metacarpals and metatarsals in all living and extinct Paridigitata: there is not a single exception to it; and the old Eocene *Dichobune*, as well as the recent *Hippopotamus*, present us with the same relation. But it may be urged against me that such a relation is certainly not to be seen in the recent Ruminantia, whose middle digits have coalesced into one single cannon bone. However, I think that the rule is even applicable to them. Although in the recent geological period the Ungulata Paridigitata, generally, acquired an exceedingly reduced skeleton, we still possess nearly all the intermediate stages between four completely developed and distinct metacarpals and metatarsals, and their reduction to two coalesced middle ones. Besides, the links which are wanting in the fossil state are often furnished by the living forms in the course of their individual development before they reach the adult age. Such links are presented by the Tragulidæ and the posterior extremities of *Dicotyles* and *Hyomoschus*. If we examine the bones of their feet at an early age, when the fourth and third digits are yet distinct, we shall see exactly the same relation as is laid down in our general rule. But even after the complete coalescence of these two metacarpals and metatarsals, some traces of the original disposition are to be detected. Examining the fore "cannon" of the typical Ruminantia (especially Deer) we shall see that one half of the proximal surface, answering to the third metacarpal, is a little higher than the other half, and always presents a produced ulnar margin, by means of which it abuts against the unciform; the same is to a certain extent seen in the back cannon, where the proximal surface for the cuboid is often a little lower than the surface for the third cuneiform.

These two middle digits (third and fourth) form the chief basis of the foot of a Paridigitate Ungulate; to these are added, on the inner and outer sides, one digit more, the second and the fifth. But so much is the skeleton reduced in the existing Paridigitata, that there exists at present only a single form (the *Hippopotamus*), represented by a single species (or two, as *Chœropotamus liberiensis* appears to be distinct), in which these two lateral digits have a true functional importance; and although the lateral digits still exist in all the Suidæ, Tragulidæ, and *Hyomoschus*, they have no real functional importance. Even in the Suidæ the two middle digits are so largely developed in comparison with the lateral ones, and all the bones of the carpus and tarsus have been so completely taken for the use of these two middle digits, that we shall be guilty of no exaggeration in stating that the Suidæ might lose the lateral digits without their locomotion being at all impaired. We even witness this process going on in *Dicotyles*—in which the lateral digits are still more reduced than in the true Suina, and they begin to disappear altogether, beginning at the external metatarsal. If the lateral digits are still retained in the Suidæ, it is chiefly owing to the fact that the Hogs live generally in marshy places and on muddy river-banks, where a broad foot is of great importance for not allowing them to sink deeply into the mud. But if, by some geological change, their habitat should be transformed into dry grassy plains, there can be no reasonable doubt that they would as readily lose their lateral digits as the Palæotheroids have lost theirs (perhaps by an analogous change of habitat) in becoming transformed into the monodactyle Horse. Should this occur only in a limited locality, and under circumstances admitting of no migration (for instance, on a large island), it is very possible that the Suidæ of this particular island might lose their lateral toes, while others, which continued to live under the old conditions, would retain theirs. If this should really occur, we should have two groups of the same family, quite similar as to the large bones of the skeleton, but dissimilar as to the structure of their feet, which is just what we witness in the two groups of the didactyle and tetradactyle Hyopotamidæ of the oldest Miocene and Upper Eocene.

What, then, are the relations of these lateral digits to the whole manus and pes, considered in their primitive unreduced condition. The inner, or the second lateral digit of the manus is supported by the trapezoid; it is not, however, limited only to this bone, but leans a little over the inner edge of the third metacarpal, and goes to touch the os magnum, which presents a special facet to this second metacarpal. We may see this typical relation in the second digit of the *Anoplotherium tridactylum* (Plate XXXVII. fig. 2), in the rudiment of the second metacarpal in the Paris *Anoplotherium* from the gypsum (see De Blainville, *Anopl.*), and in the very complete fore foot of *Hippopotamus* and *Hyopotamus* (Plate XXXVII. figs. 1 & 20, II. *t*, *m*). In the posterior limb, the inner or second metatarsal is supported entirely by the second cuneiform (the homologue of the trapezoid), and by the tibial edge of the great or third cuneiform (the homologue of the os magnum), as may be seen in *Hippopotamus*, figs. 9 & 10, *Anoplotherium*, fig. 11, *Hyopotamus* (Plate XXXVIII. fig. 2), and *Anthracotherium**.

The outer or fifth digit of the manus and pes in all Ungulata Paridigitata (and, in fact, in all existing Mammalia) is supported by the same carpal bone as the fourth. There is not a single exception to this rule; and in all Mammalia, wherever the fourth and fifth digits of the manus and pes are present, they are always supported by one bone —the unciform in the manus, and its homologue (the cuboid) in the pes.

Seeing that the full number of digits in Mammalia is five, while the number of carpal and tarsal bones which give support to them never exceeds four—three inner digits being supported each by a separate bone, while the two outer are always supported by a single carpal and tarsal bone—the question may arise, is this relation primitive for all Mammalia? or is it a result of coalescence of two outer carpal and tarsal bones into one? As we have not the slightest notion of the skeleton of the first mammals, nor even of the geological time when they made their appearance, the solution of this question is not to be expected now. Turning to some of the Amphibia and Reptilia with completely developed digits, we generally, or at least very often, find, as has been proved by the beautiful researches of Gegenbaur, that each of their digits in the manus and pes is supported by a special carpal and tarsal bone, there being five distinct bones in the second row in the manus and pes. Now it is very possible that the first progenitor of the class Mammalia had also five carpal and tarsal bones in the second row, or, what is more probable, seeing that there is not a single instance of these two outer bones being found separate in any mammal, living or fossil, that their coalescence was effected before the evolution of the first truly mammalian type, and that they passed into this class already coalesced.

I have already mentioned that, beginning with the mammals of the oldest known Eocene deposits, the oldest mammals of whose skeleton we are able to form a tolerably clear idea (the oldest Mammalian remains, though proving the existence of the class as far back as the Jurassic and even the Triassic period, have not yet furnished the slightest clue as to their skeleton), we meet always with Ungulates which belong unmistakably to the one or the other series; a fossil Ungulate may be at once said to belong either to the Paridigitate or Imparidigitate division; we have not a single form in which the characters of the two groups can be said to be mingled together, or which could be reputed to be the progenitor of both these great divisions of the Ungulata. Some of the early Eocene Paridigitata and Imparidigitata seem undoubtedly to be more nearly related, and have more common characters, than the greatly reduced forms we meet with in the recent epoch; but this shows only, if we imagine these two series to be diverging lines meeting in some old Cretaceous Ungulate, that they occupy certain positions on these two different lines nearer to the point of divergence, but still so far from it that all the intermediate links had time to be completely destroyed before the Eocene period. We may imagine that in the Cretaceous epoch there existed an Ungulate form with a very complete skeleton and five digits to the manus and pes; from this common form the divergence of Paridigitata and Imparidigitata may have been effected in such a way that, with the commencement of the reduction of the skeleton of this typical primary Ungulate, the chief development fell in one case on the middle (3rd) digit of the manus and pes, the laterals becoming more or less reduced and arranged symmetrically on both sides of this central digit of the manus and pes, so as to originate the series of Imparidigitata; while in the other case the chief development fell on the two contiguous middle digits of the manus and pes (the 3rd and 4th), giving rise to the series of Paridigitata. But as the overdevelopment of a single middle digit, to such an extent as to support the body effectually, is a task much more difficult to the organism than the development of the two middle digits to a comparatively less extent, the reduction of the Paridigitate skeleton proceeded at a much quicker rate than that of the Imparidigitate; and while we meet with many animals of the Paridigitate series having only two digits in the Eocene, the Imparidigitata have always three. In the Miocene epoch, the two middle reduced digits of Paridigitata have already coalesced to form a single digit, the cannonbone of Ruminants; but the most reduced member of the Imparidigitata, the *Anchitherium*, still walked on three toes, though the laterals began to be greatly reduced; and it is only in the later Miocene and the Pliocene periods that, with the appearance of the *Hipparion* and Horse, the skeleton of the Imparidigitata attained as great a reduction as the skeleton of Paridigitata did in the earliest Miocene, *Gelocus* (Aymard) being the first Paridigitate with a complete cannonbone in the adult. In the skeleton of this Ungulate progenitor, before the divergence of the two series was effected, we may imagine a pentadactyle manus and pes constructed in the way given in the following scheme.

---

* This relation is very characteristic, not only as regards Ungulata, but nearly all Mammalia.

Scheme of the Ungulate Manus and Pes.

Manus.					Pes.				
Unciform.		Magnum.	Trapezoid.	Trapezium.	Cuboid.		Cuneif. 3rd.	Cuneif. 2nd.	Cuneif. 1st.
Metacarpal 5th.	Metacarpal 4th.	Metacarpal 3rd.	Metacarpal 2nd.	Metacarpal 1st.	Metatarsal 5th.	Metatarsal 4th.	Metatarsal 3rd.	Metatarsal 2nd.	Metatarsal 1st.

The two outer digits of the manus and pes are supported by one bone—the unciform in the manus, the cuboid in the pes; the three following digits in the manus were supported, the *third* by the os magnum, the *second* by the trapezoid, the *first* by the trapezium; and in the pes each of the inner digits was supported by its corresponding cuneiform. The reduction of the manus and pes commenced at the first or inner toe; and we have not a single living or extinct Ungulate presenting this first digit developed; nay, more, I know of no positive case where even a rudiment of the first toe is present. All the bones described as such rudiments have turned out, on close inspection, to be the trapezium or the first cuneiform* mistaken for the rudiment of the first digit. This is constantly the case in regard to the rudiments described in the 'Ossemens Fossiles.'

Fortunately, even in the recent period, there still exists an Ungulate upon which we may well study the structure of the typical Paridigitate manus and pes. This is the *Hippopotamus*: no trace of the first digit is left in the fore or hind limb; but, owing to the very complete development of the remaining four digits, they must have retained their typical relations to the bones of the carpus and tarsus. Looking at the fore foot of the *Hippopotamus* (Plate XXXVII. fig. 1) we perceive that the two middle digits are mutually interlocked in the manner described above as common to all Paridigitata. The two outer digits, the fourth and fifth, are supported by the unciform; the third is supported by the os magnum, and gives besides, at its ulnar margin, a projecting beak, by means of which it hangs on to the unciform; the second digit goes a little higher than its neighbours, is supported by the trapezoid, and touches a small facet on the radial side of the os magnum; the first digit is entirely reduced, and its proper carpal bone, the trapezium, assists to support the second digit.

What do we see in the hind foot? The cuboid (Plate XXXVII. fig. 9, *cb*), which is the homologue of the unciform, supports the fourth and fifth digits; the interlocking of the two middle metatarsals is effected in the usual way, the fourth giving a projection which enters into a concavity of the third; the third cuneiform (c_3) (the homologue of the os magnum) supports the third metatarsal; the second metatarsal is supported by the second cuneiform (c_2), and its tibial margin touches the third cuneiform (just as the homologous parts on the fore foot do); the first digit is entirely lost, and its typical tarsal bone, the first cuneiform, aids in supporting the second digit (Plate XXXVII. fig. 10, c_1).

---

* If this absence of even a rudiment of the first digit is really constant among fossil and living Ungulata, it may possibly be supposed that at the branching off of the Ungulate division this first digit was already reduced and even entirely lost.

This should be the place to consider the structure of the feet in the Suina; but, as in the recent members of this family, owing to the overdevelopment of the middle digits, the typical relation between the bones is a little changed, I will describe it after having treated those Paridigitata which preserve this typical relation unchanged.

Of the fossil Paridigitata whose skeleton is known to us with any thing amounting to completeness, we have only the *Anoplotherium* and *Xiphodon*; and we shall see by-and-by with what wonderful persistence the typical relations are adhered to in the skeletons of these animals, notwithstanding the great reduction of the number of their metacarpals and metatarsals.

As the *Anoplotherium tridactylum* is certainly a less-reduced form than the species from the gypsum, and as, except a sketch in Gervais's 'Paléontologie Française,' there are no good drawings of its extremities, I represent them on Plate XXXVII. figs. 2, 11, from the original specimens of Bravard now in the British Museum. Though the number of digits on the fore and hind limbs is odd, it is nevertheless a very typical Paridigitate, and differs from the Paris *Anoplotherium* only in this respect, that the second digit, which is represented only by a small rudiment in the animal from Montmartre, is developed to a complete (though short) digit in the *Anoplotherium* from the lignites of Vaucluse. The manus of the *Anoplotherium* is so well described by Cuvier that I will not enter into any details, and only point out its chief peculiarities. As seen in Plate XXXVII. fig. 2, this manus is entirely true to the general type: the interlocking of the two middle metacarpals is effected in the same way as described above; the fourth metacarpal is supported by the unciform; the third hangs to the os magnum, and sends a prolongation of its ulnar margin to meet the unciform; the second, though too short to touch the ground, is complete and supported by the trapezoid, and it sends a projection to articulate with the os magnum; the trapezium aids in supporting the short second digit. At the outer margin of the foot there exists a rudiment of the fifth digit, leaning against the unciform and the ulnar margin of the fourth metacarpal.

The pes of *Anoplotherium tridactylum* (Plate XXXVII. fig. 11) shows us the same typical persistence in the relation of the bones. The interlocking of the two middle metatarsals takes place, as usual, by a process from the fourth fitting into an excavation of the third metatarsal; this last is supported by the third cuneiform (c_3). As the second digit is developed, the corresponding bone, the second cuneiform (c_2), very small or nearly obsolete in the Paris *Anoplotherium*, is largely developed in the *A. tridactylum*, and supports the second digit; the first digit is absent, and its tarsal bone, the first cuneiform (c_1), aids in supporting the second digit.

As the chief difference between the *Anoplotherium* from the gypsum of Paris and the *A. tridactylum* lies in the development of the second digit and its corresponding carpal and tarsal bones, I have represented the distal surface of the navicular (to which the cuneiforms are attached) of the tridactyle form (fig. 19) and of the Paris *Anoplotherium* (fig. 17); the navicular (fig. 18) is from the same locality as the tridactyle one; and though undoubtedly belonging to a didactyle *Anoplotherium*, the intermediate facet for the second cuneiform still presents some development, while in the Paris specimen it is exceedingly small and is even absent in some specimens; indeed it seems that the second cuneiform, being very small, did not always touch the navicular; and this led CUVIER into the erroneous belief that this bone was altogether wanting*.

The manus and pes of *Xiphodon* (Plate XXXVII. fig. 3) present exactly the same peculiarities: though reduced to only two metacarpals and metatarsals, these two are in no way adapted more completely to the distal surface of the carpus, and are supported only by their typical carpal and tarsal bones. The persistence of typical relations is so great that even the rudiment of the second metacarpal, though a mere bony nodule, persists not only in its articulation with the trapezoid, but even with the radial facet of the os magnum (as seen in Plate XXXVII. fig. 3, II., *m*, *t*), as truly as in the case of the complete second metacarpal in the four-toed foot of a Hippopotamus.

In the pes, as far as I am able to see by the figures of CUVIER and DE BLAINVILLE, the relation between the metatarsal and tarsal bones is quite such as we laid it down in our general scheme. There are three distinct cuneiforms; the third metatarsal is supported entirely by the third cuneiform; and though there is only a small rudiment of the second metatarsal, nevertheless this rudiment has not surrendered its typical articulation, and retains the whole of the second cuneiform for itself; the first cuneiform is articulated upwards with the scaphoid, touches the posterior part of the second cuneiform, and is articulated lower down with the rudiment of the second metatarsal, presenting in this way entire agreement with the typical structure of a Paridigitate tarsus†.

Now, if we turn to CUVIER (Oss. Foss. v. 4to ed. p. 181), we shall see that he noticed the three cuneiforms in *Xiphodon*, calling only the first (marked *e*) "osselet surnuméraire;" he did not notice the true rudiment of the second metatarsal (DE BLAINVILLE is entirely wrong in saying that there were only two cuneiforms, *Anopl.* p. 50); he did not describe or mention the rudimentary second and fifth metatarsal, though he very correctly noticed the corresponding bones in the metacarpus.

After this brief notice of the structure of the metapodium in the fossil Paridigitata, we may proceed with the description of the same parts in *Diplopus* and *Hyopotamus*; but I wish, before doing so, to take a short survey of the same part of the skeleton in the remaining living representatives of the Paridigitate series, the Suidæ and Ruminantia.

---

* Passing through Paris, I tried to settle this question; and in fact there exists in the 'Galerie de Paléontologie' a nearly complete foot with the three cuneiforms. It is in a block of gypsum, and placed high on the top of the wall-cases in the gallery.

† I find on the posterior part of the distal articular surface of the cuboid of *Xiphodon* a small facet clearly destined for the rudimental fifth metatarsal.

The general conclusion to be drawn from our survey of the fossil forms, is that they exhibit an extreme uniformity in the structure of their metapodium, and that these uniform and typical relations between the metapodium and the bones of the carpus and tarsus are remarkably constant, and, as regards the fossil forms, unpliant and rigid. Even with the utmost reduction of the metapodium in *Anoplotherium* and *Xiphodon*, the typical relation between the two remaining metacarpals and metatarsals remains just the same as it probably was in their tetra- or pentadactyle ancestors; so long as even a rudiment of a metacarpal or metatarsal remains, it holds just the same relation to the supporting bones as if it were complete. We meet with no distinct adaptation by means of which the median metacarpals and metatarsals which are left after the dropping off of the laterals, enter into a more complete articulation with the remaining bones of the carpus and tarsus. Considering, for instance, the two slender separate metacarpals and metatarsals of *Xiphodon*, we must confess that a foot so badly adapted for the use of a swift animal is rarely to be met with The middle digits, being unankylosed, are liable to be broken separately by a much less exertion of force than it would require to break the two coalesced middle digits of a Ruminant; besides, seeing in what manner the whole weight of the body is transmitted to the two middle digits, we shall find that it is not effected in such a way as to ensure the most complete and stable equilibrium. To effect this we might expect that the proximal ends of the two remaining metacarpals (Plate XXXVII. fig. 3) would be enlarged to such a degree as to underlie the whole distal breadth of the carpus; in this case the weight of the body would be transmitted much more equably and effectually to the two middle digits of the metacarpus. However, we see nothing of the kind: the transmission of the weight of the body is effected only by the two bones of the second row of the carpus; and the two useless rudiments remaining on both sides, and occupying the whole trapezoid and a large facet of the unciform, diminish by so much the stability of the foot, in comparison with an arrangement in which the facets occupied uselessly by them should be taken by the functional middle digits. We meet with exactly the same relation in the pes; so that it will be needless to recapitulate in reference to it all we have said in reference to the manus. The same may be, to a great extent, said of the *Anoplotherium*, though the digits which remain are so stout and short that the want of stability of the foot is not so clearly shown by this form as by its slender congener.

On the whole we may, with sufficient probability, say that, while in these two genera the reduction of the manus and pes was going on and the lateral digits aborted, the remaining middle digits did not adapt themselves as fully as could be imagined* to altered circumstances of life and to a different distribution of weight of the body; they remained too true to ancestral traditions; there was no pliancy in their organization which, by adapting them more fully to altered conditions of life, would have enabled them to carry on successfully the struggle for existence with other competing genera.

---

* And as we actually see in other genera which outlived *Anoplotherium* and *Xiphodon*.

And these last, as we shall presently see, being better adapted to altered conditions of life, got the upper hand, multiplied largely in specific and generic forms, and peopled the earth with their successors, while *Anoplotherium* and *Xiphodon* died away without leaving any[*]. In this inflexibility and rigidity of organization, in this inability to alter it as completely as the competing genera were able to do, lay perhaps one of the causes of the extinction of some genera and their replacement by others. All that I attempt here is to show in what peculiarities of structure this rigidity of some genera and pliancy of others consisted. I do not wish to put this as the *only* cause, but as one of the *many* still unknown causes which led to the extinction of so many animals that preceded the present population of the earth.

I have adduced here only such cases as are known and described; but having carefully examined large collections of bones from the Eocene and Miocene deposits, I have been struck with the recurrence of similar facts. Trying to reconstruct the extremities of some Paridigitata of the Lower Eocene from Mauremont and Egerkingen, and of Miocene forms from Rochette, I could distinctly perceive that all genera which have left no direct successors, and which are entirely extinct, present the same rigidity and persistence of the typical relations; on the contrary, those which have representatives in the living creation, their direct successors, exhibit much more pliancy and much better adaptation to altered circumstances of locomotion, along with the reduction in the number of digits.

Before proceeding to consider the two remaining groups of Paridigitata, the Ruminantia and the Suina, we may draw the attention of the reader to the fact that these two groups of Paridigitata are the only ones[†] which now people the earth; there is no greater diversity than this; and every living Paridigitate (if we except the Hippopotamus) is always clearly a ruminant (including the Tragulidæ and Camelidæ) or a *Sus*. How striking is this poorness of different types if we compare it with the rich and diversified forms presented by the recent Carnivora or Rodentia. The extreme diversity of generic forms and specific modifications, coupled with the enormous range of distribution of living Paridigitata, produces a false impression of the diversity presented by this order; but in reality there is no such diversity, and all the extremely rich assemblage of Paridigitate Ungulates that people the earth in our time are only the result of the modification of two typical forms, the Suina and the Ruminantia. The latter term is a very objectionable one, as the faculty of rumination has nothing to do with the skeleton, and in reality it would be no wonder if some of the Imparidigitates possessed the same faculty. As the teeth have so great a value in systematic zoology, it would be perhaps more advantageous to distinguish all Paridigitata into those which have tubercular and those which have crescentic teeth. To the first division will belong all the existing Suina and the Hippopotamus; to the second, the remaining Paridigitata, which all possess, more or less completely, the faculty of rumination coupled with the absence of incisors (Camel?) in the premaxillaries. Such a division of Paridigitata would allow a place in the zoological scale to the extinct forms which were distinguished by the non-confluent metapodium, and the presence of incisors in the premaxillaries, and very probably did not ruminate.

---

[*] The reduction of the limbs in *Anoplotherium* and *Xiphodon* is so great that I regard them only as the last representatives of dying-out branches that did not leave any direct descendants.

[†] If we except *Hippopotamus*—this last remnant of a Paridigitate series once rich in generic forms, but which is now reduced to only two distinct groups.

We shall now proceed to cast a comparative glance at the structure of the feet in both these divisions as they exist in our own time, and endeavour to discover if their structure does not present some characters which show that they are better adapted for new circumstances of life than were their Eocene and Miocene predecessors; and that to this better adaptation may be, in part, ascribed the victory they obtained in the battle of life, and their spreading over all the surface of the globe.

As the Paridigitata with tuberculated teeth are represented, in the recent period, only by the Suina, and those with crescentic teeth only by the Ruminantia, we shall have to confine ourselves to these two orders; in the latter we shall particularly call the attention of the reader to the Tragulina, as the less reduced members of this family, and therefore more likely to furnish us with typical characters.

The true Suina have four complete digits in their manus and pes, but only the two middle ones are subservient to the purpose of locomotion; the laterals are always so reduced that they do not regularly touch the ground, or only do so on muddy soil, when the foot sinks deeply into the earth. According to the general rule laid down for all the Paridigitata, the interlocking of the two middle (third and fourth) metacarpals in the manus is effected as usual; the fourth digit is supported by the unciform, while its radial upper margin is fitted into an excavation on the ulnar side of the third metacarpal, which, by means of an ulnar process of its upper margin, articulates with the unciform, while its proximal surface is supported by the os magnum (see figs. in CUVIER, 'Oss. Foss. Atlas,' and DE BLAINVILLE, 'Ostéographie, *Sus*,' also our fig. 4, Plate XXXVII.). However, in examining more attentively this proximal surface of the third metacarpal of the Hog, we remark something quite new, and not met with in most of the fossil Paridigitata. Owing to the over-development of the middle digits, the radial side of the third metacarpal (Plate XXXVII. fig. 4) has spread inwards and pushed the second metacarpal away from its typical articulation with the os magnum; nay even more, this second metacarpal has yielded one half of the surface of its carpal bone to the encroachment of the third digit; this last, besides the magnum, occupies now one half of the trapezoid—a new fact in the history of the Paridigitate foot that had important consequences. To show the reader more clearly that this modification is a recent one, we turn to the fossil Suidæ. Unhappily, our knowledge of their skeleton is very imperfect; and while genus after genus (not to speak of species) of the fossil Suidæ have been created merely on dental, often very slight and unimportant, characters, the study of their skeleton has been much neglected. As far as I am aware, not a single bone of their skeleton was figured or discussed comparatively until the appearance of Professor GAUDRY's work on the Fossils of Pikermi*.

However, I was so fortunate as to see many bones of the skeleton of the Miocene Suina, distributed into divers genera, in the collections of Paris and London; and on comparing the third metacarpal of the *Palæochœrus*† (Plate XXXVII. fig. 6) from Auvergne, and the *Chœromorus*, Lrt., from Sansans, with that of the recent Suidæ, I found that this broadening of the third metacarpal did not exist in *Palæochœrus* nor in the *Chœromorus*, the second digit taking for its support the entire surface of the trapezoid. Plate XXXVII. fig. 6 represents a third metacarpal of *Palæochœrus*; and by comparing it with fig. 4 we immediately perceive the difference. This broadening of the metacarpals, with the purpose of taking the whole of the distal surface of the second row of bones of the carpus, took place in the Suina only after the middle Miocene epoch. But, among the recent Hogs, we have one more advanced form which, in this character, stands to the other Suidæ nearly in the same relation as the Suidæ stand to the Palæochœridæ; this is *Dicotyles*. The structure of its fore limb agrees entirely with that of *Sus*, only the lateral metacarpals are reduced a step further; and looking at fig. 5, Plate XXXVII., we shall see that the enlarged third metacarpal has taken, not the half, as in *Sus*, but the whole of the distal surface of the trapezoid, the second metacarpal being pushed entirely away from its typical carpal bone. Moreover, this facet for the trapezoid (as in fig. 4) is transformed from an oblique into a horizontal one, thus giving better support to the third digit; while the corresponding distal surface of the trapezoid instead of having a spear-shaped form, as in the Hog (fig. 4, *t*), is quite flat in *Dicotyles* (fig. 5, *t*). The trapezium (fig. 5, *tz*) is greatly reduced, has no distinct articular facet on the trapezoid, and is disappearing altogether, without coalescence with the trapezoid. Thus, then, we find that, in the Miocene Pigs, the whole trapezoid is, according to the typical relations, taken by the second digit; in the recent Hog only half of its distal surface is left for the second digit, and none at all in *Dicotyles*.

On the outer side of the manus, the relations are much simpler, as the fourth and fifth metacarpal are supported, in all Ungulata, by a single bone, the unciform; therefore, by the gradual broadening of the fourth metacarpal, the outer or fifth digit is pushed to the outer side of the distal surface of the unciform, until, in the Hog and in *Dicotyles*, it occupies only a small lateral and outer facet on this bone, in such a way that the fifth digit has practically no upper carpal facet, but is suspended laterally to the outer side of the unciform; and this lateral position is more pronounced in *Dicotyles* than in the Hog, in consequence of the greater reduction of the former.

---

* GERVAIS, 'Paléontol. Française,' has figured a third metacarpal, which is very interesting, as it shows none of the broadening of the radial margin so characteristic of *Sus*. It is from the right side, while all figured by me are left.

† In its dental characters, as well as in its skeleton, *Palæochœrus* stands so near to the Hog that even their generic distinction might be questioned. The *Chœromorus*, being also a true Hog, stands further from the recent Suidæ; one of the very curious characters of this remarkable genus is the central ridge of the distal extremities of the metacarpals and metatarsals, which, instead of encircling the whole extremity, is limited to its back part only; the first phalanges are modified accordingly.

Moreover, if we examine attentively the proximal surfaces of the two middle metacarpals in *Dicotyles*, we shall see that they are much more joined together than in the common Hog or any other *Sus*; their inner flat sides are so closely united that it will require only a little step further to make them coalesce; and as the os magnum and trapezoid are now both resting on one metacarpal they cannot remain long distinct, but must coalesce: if this should occur, we should have a structure nearly analogous to, and hardly to be distinguished from, that of a typical ruminant.

If we turn now to the structure of the *pes* in the Paridigitata with tuberculated teeth, or Suina, we shall meet with precisely the same phenomena; and the homologous bones of the manus and pes undergo a strikingly similar course of variation.

The two middle digits of the *pes* interlock, in the usual way, by a process from the fourth metatarsal, which fits into an excavation of the third. The cuboid supports the two outer digits, the fifth and fourth; the third digit is supported by the third cuneiform. If we compare the third metatarsal of the recent Hog (Plate XXXVII. fig. 12, III.) with the same metatarsal of *Palæochœrus*, fig. 12′, and of *Chœromorus*, we perceive just the same difference as in the homologous bones of the manus. While in *Palæochœrus* the third metatarsal is confined entirely to the third cuneiform*, leaving the second cuneiform for the support of the second metatarsal, in the Hog (fig. 12, III. c_3, c_2) this third metatarsal is greatly enlarged; it has pushed the second digit away, and encroached on nearly the whole of the distal surface of the second cuneiform, leaving only a very narrow facet of this bone for the second metatarsal (fig. 12, II. c_2), which is now chiefly supported from behind by the wedge-shaped first cuneiform.

On the outer side of the pes, the enlargement of the fourth metatarsal has taken the greater part of the distal surface of the cuboid, the fifth metatarsal being pushed very much backwards, and being supported partly by a small facet on the distal surface of the cuboid, and partly by a posterior prolongation to the beak-like downward process of the same bone. The pes of the *Dicotyles* shows us the same disposition in an exaggerated form; the inner side of the third metatarsal (Plate XXXVII. fig. 13, III.) has completely occupied the second cuneiform, so that the second digit is supported only from behind by the first cuneiform. On the outer side, the fifth digit is completely lost; or, if a rudiment of the fifth metatarsal remains, it is generally a flat elongated bone attached to the outer side of the fourth metatarsal, and having no articular surface on the cuboid, which is taken up by the over-developed fourth metatarsal. Besides, the two middle digits have coalesced in the whole upper half of their length, simulating the cannonbone of a Ruminant. The navicular and cuboid are still separated, but are very firmly pressed together; and now, both these bones, having the coalesced metatarsal below them, cannot have much separate movement, and their coalescence, as well as that of the second and third cuneiform, is only a question of time, the modification going on uninterruptedly in the direction of the greater reduction of the limb-bones.

---

* As the hind limbs are always more reduced than the fore, it seems that, even in *Palæochœrus*, the third digit encroached in a perceptible way on the second cuneiform.

Can the general tendency of this steady reduction be doubtful? Is not the fact eloquent enough, that, proceeding from the middle Miocene times until the recent period, we meet with a whole series of Suina in which the skeleton is gradually more and more reduced, until it culminates in the Post-tertiary time in *Dicotyles*, a form very analogous, in the structure of its limbs, to the Ruminants, whose middle digits are quite ready to coalesce into a cannonbone, and the laterals to drop off? Indeed, this has begun in the posterior limb, in which reduction is always in advance, and on its outer side, which is generally more reduced than the inner. If any inference from one series of phenomena is allowed to be applied to another, then, inasmuch as the Paridigitata with CRESCENTIC TEETH, or the recent Ruminantia, proceeding from tetra- or even pentadactyle forms, arrived in the Miocene period at didactyle forms, in which the coalescence of the two middle digits simulates monodactylity, we have a full right to infer, seeing the parallelism of these two groups, that the Paridigitata with TUBERCULAR TEETH have followed just the same line of reduction. And if nature should be allowed to follow its course, or if man had made his appearance only in the Post-quaternary instead of the Post-tertiary period, he would no doubt have found only two groups of Paridigitates remaining, one with crescentic, the other with tubercular teeth, but both having a cannonbone in their fore and hind limbs, and no lateral digits. These two groups of Paridigitates undergo exactly parallel modifications in the course of time, as far as their limbs are concerned—only in the group with crescentic molars these modifications have gone on much more rapidly than in the parallel group with tubercular teeth. The cause of this greater rapidity lay very probably in the more specialized, instead of an omnivorous, diet, and was perhaps influenced by the commencing faculty of rumination, which gave them an enormous advantage over the other group, by allowing them to store food in their paunch in the most favourable, or least dangerous, part of the day, and chew it afterwards when retiring to rest.

If we turn now to the Paridigitates with crescentic teeth, represented in our times only by the living Ruminantia, we meet in the typical (which in this case means the most reduced) genera both middle metacarpals and metatarsals coalesced so as to simulate a monodactyle foot, forming the so-called cannonbone. The rudiments of the lateral digits are mostly lost (in *Bovidæ* and *Antilopidæ*) or retained only as small filaments of bone, having no articulation with the carpal or tarsal bones, but merely pressed to the outer and inner sides of the two middle digits. The trapezium is entirely lost; the trapezoid is confluent with the magnum *. In the tarsus, the navicular is confluent with the cuboid, and the second cuneiform with the third; the first remains nearly always separate, and in case of confluence with the coalesced second and third cuneiforms, as in the Giraffe, the division is clearly seen. This is the general structure of the foot in the typical Ruminantia, or the most reduced Paridigitata with crescentic teeth; but fortunately we have still a living form which stands to the typical Ruminantia nearly in the same relation as our *Dicotyles* would stand to the Post-quaternary Suinæ with a cannonbone. The parallel is really complete, with the exception of some small points*. This living form is the *Hyomoschus aquaticus*, hardly distinguishable from its fossil congener of the Middle Miocene. If we examine the manus of this animal (Plate XXXVII. fig. 8), from the inner side, we shall meet with characters common to all Paridigitata. The interlocking of the two middle metacarpals is effected in the usual way; the inner, or radial, margin of the third is enlarged in the same way as we saw it in *Dicotyles*—only the two carpal bones which support this enlarged third metacarpal, the magnum and trapezoid, are already confluent (fig. 8, *m* & *td*); the reduced, but still complete, second digit has a small facet on the back part of the coalesced trapezoideo-magnum. On the outer side of the manus, the large fourth metacarpal is supported by the unciform, and the distal surface of this bone gives also a small facet to the reduced and thin, but still complete, metacarpal of the fifth digit.

---

* Except in *Camelidæ*.

The pes of *Hyomoschus* will show us something similar to what we have seen in the manus. As seen in fig. 14, Plate XXXVII., the inner side of the third metatarsal is enlarged, and has taken the whole of the second cuneiform, the second metatarsal being supported entirely by the first cuneiform, which is distinct, while both the others have coalesced mutually and with the navicular (c_3+c_2+n, fig. 14).

On the outer side of the pes we find that the large fourth metatarsal has taken nearly the whole distal surface of the cuboid; however, it leaves a very small facet for the articulation of the complete fifth digit. The length of the lateral metacarpals and metatarsals nearly equals that of the middle ones, though, owing to their thinness and the want of direct firm support from the carpals and tarsals, they are, as it seems, not subservient to locomotion. The middle metatarsals are confluent in the adult.

In the Tragulidæ (Plate XXXVII. figs. 7 & 15) the middle metacarpals and metatarsals are distinct in the young, even after their complete ossification; in this state we may ascertain that their mutual interlocking is effected as in all other Paridigitata. The inner margins of the third metacarpal and metatarsal are enlarged even more than in *Hyomoschus*, and their relation to the trapezoid and second cuneiform is altogether the same. The lateral digits persist during the whole of life as filiform bones on both sides of the middle cannonbone. Although of the same length as the cannonbone, they are useless for locomotive purposes, owing to their extreme thinness. At last, in the typical Ruminantia, the two middle metacarpals and metatarsals coalesce into the cannonbone during the process of ossification. All particulars we have remarked in the Tragulinæ are exaggerated in the true Ruminants. The trapezoid and the second cuneiform are always, even in the cartilaginous state, confluent with the magnum and third cuneiform, and can be detected only as distinct points of ossification. The rudiments of the lateral digits are generally preserved as slender elongated bones in the metacarpus, especially in Deer, much more seldom in the metatarsus. In the fossil Ruminantia from Auvergne these lateral rudiments are present, as a rule, on both the fore and hind limb (Plate XXXVII. fig. 16, II.). The rudiment of the fifth metatarsal is usually free, and has even a small facet on the cuboid; while the second metatarsal, being jammed in between the inner enlargement of the third metatarsal and the posterior beak-like prolongation of this digit, has generally coalesced; but its proximal extremity is mostly free, and articulated with the first cuneiform (and this is sometimes to be seen even in living Ruminantia).

---

* The chief are these:—the trapezoid is confluent with the magnum, while it is only preparing to become so in the anomalous *Dicotyles*; the navicular of the pes is confluent with the coalesced second and third cuneiforms (as in all the Tragulidæ); the fifth digit of the pes is completely developed, not lost, as in *Dicotyles*. The articular ridge of the distal end of the metacarpals and metatarsals is confined only to the palmar side, and the first phalanges are modified accordingly. If we remember that some of the ancient Pigs, as *Chæromorus*, show just the same smoothness of the distal ends of the metapodium, the parallelism of both groups of Paridigitata appears to hold good, even in the slighter details.

The upper and posterior beak-like prolongations of the middle metatarsals of Paridigitata constitute a very characteristic feature of these bones; they grow larger and larger with the reduction of the pes, and are firmly pressed together by a special process of the cuboid and the first cuneiform in those genera in which locomotion is almost entirely performed by the two middle digits. Finally they coalesce, and the confluence of the metatarsals seems to proceed from these processes downwards, as is to be seen at a certain age in the metatarsus of *Dicotyles*.

Metacarpus and Metatarsus of Hyopotamus *and* Diplopus.

Having thus discussed at some length the shape and mutual connexions of the bones which compose the fore and hind limbs in the chief fossil and living Paridigitata, our task is made much easier in reference to *Diplopus* and *Hyopotamus*; and without dwelling too long on the description of very minute particulars of these bones, which to a certain extent are visible in the Plates, I shall merely state the chief features they present to the observer, and the points of agreement or difference with the corresponding bones of allied genera.

I begin with the metacarpals of *Hyopotamus*, or the tetradactyle form, and will afterwards pass to the didactyle *Diplopus*. The restoration of the manus of *Hyopotamus* from Puy is given in Plate XXXVII. fig. 20, ½ nat. size, and the upper part of the same manus, fig. 5, Plate XXXVIII. The separate bones belonged to different individuals, and were not found in connexion. The fourth metacarpal especially is defective; but it is the only specimen of this digit I could find in the collections from Puy; it comes from a very young individual, and is therefore too small for the adult unciform by which it is supported. I have seen the same bones from Hempstead, but somewhat rolled.

The interlocking of the two *middle metacarpals* is effected in the usual way, the radial margin of the fourth being thrust under the ulnar prolongation of the upper margin of the third (Plate XXXVIII. fig. 5). This ulnar prolongation of the third metacarpal going to meet the unciform is very oblique in the *Hyopotamus*; its axis forming, approximately, an angle of 45° with a horizontal line. In the Suidæ, as well as in the corresponding bone of *Diplopus* (Plate XXXVIII. fig. 6, III.), this projection is much more inclined (perhaps 30° with the horizon). The reason of this difference is given by the unciform, as the radial inferior truncature of this bone (Plate XXXVIII. fig. 5, *u*), to which the projection of the third metacarpal is articulated in *Hyopotamus*, becomes nearly vertical, and helps to constitute the inner radial wall of the same bone in *Diplopus* (Plate XXXVIII. fig. 8).

The *proximal surface* of the third metacarpal (fig. 5, III.) has an elongated, somewhat triangular, flat facet for the os magnum; this upper surface is sloping inwards, so as to allow the second metacarpal to lean laterally on this margin, and reach its facet on the os magnum, as seen in fig. 5. In *Diplopus*, on the contrary (fig. 6, III.), this upper radial margin of the proximal surface is produced upwards (as in *Palæochœrus*, Plate XXXVII. fig. 6); and therefore I think that, in the didactyle form, the rudiment of the second digit could not reach as high as the os magnum.

The *ulnar side* of the third metacarpal has an anterior reniform and a posterior oval facet; both articulate with corresponding facets on the radial side of the fourth digit. In the didactyle *Diplopus*, this anterior reniform facet is excavated into a deep hole for a corresponding large projection of the fourth metacarpal, as seen in Plate XXXVIII. fig. 6: thus the interlocking of the two middle digits is much closer in the didactyle genus; and this is quite natural, as the foot, having no lateral digits, required a firmer structure.

The *radial side* of the third metacarpal in *Hyopotamus* has on its anterior part a tolerably long (7 millims.) facet, which is uninterruptedly united with the somewhat sloping radial margin of the proximal surface. This facet is destined for the second metacarpal, which has a corresponding surface on its inner (ulnar) side; the bone on this side is flattened by the pressure of the complete lateral digit, as may be seen in the sections of the four metacarpals given below the fig. 5. If we compare this part of the third metacarpal with the corresponding region in *Diplopus* (fig. 6, III.), we shall see a great difference. In this last genus, as there is no lateral second metacarpal, but only a rudiment of it, we find a deep depression, with small longitudinal facets, where the rudiment (seemingly a nodular bone, as in *Anoplotherium*) adhered to the third metacarpal. We meet with an exactly similar hollow on the inner (radial) side of the third metacarpal in *Xiphodon*. On the upper and front part of this third metacarpal is a rough tuberosity for the tendon of the extensor carpi radialis muscle; this is not so prominent in the same bone of *Diplopus Aymardi* (fig. 6), perhaps owing to the younger age of the individual to which the third metacarpal of fig. 6 belonged.

The *fourth metacarpal* (Plate XXXVIII. fig. 5, IV.) of *Hyopotamus*, though represented very badly by a proximal half of the bone belonging to a young individual from Puy, shows, nevertheless, nearly all we require to know about it.

The *proximal surface* is flat, and has the shape of an isosceles triangle. On the radial upper margin we have a thickening at the point where the fourth digit is thrust under the ulnar prolongation of the third. The ulnar, or outer, side of the fourth metacarpal has two distinct facets, an anterior and a posterior one, for the articulation of the outer or fifth metacarpal.

The general shape of both middle digits in *Hyopotamus* is very flat in front, with two tolerably sharp edges, which form the outer and inner border of each metacarpal; the two inner, or contiguous, edges are formed by the metacarpals being pressed against each other in the axial line, while the outer edges result from the pressure of the lateral digits on the two middle ones from without and within (see fig. 5, and section). In the *Diplopus*, as we shall see hereafter, we have only the contiguous edges, while the outer sides of both metacarpals are rounded and smooth, there being no lateral digits. The section of the four metacarpals given below fig. 5 may give an idea of the flatness of these bones in the middle: it may be possible that they are somewhat flattened by pressure; but in the living Hippopotamus the metacarpals are perhaps relatively as flat. The length of the third metacarpal (drawn in outline) from Puy is given by a complete specimen in the collection of M. AYMARD. I have also several rolled specimens of both middle and internal lateral digits from Hempstead.

The distal ends of the two middle metacarpals (Plate XXXVII. fig. 20) are quite smooth in front; but on the posterior or palmar surface of each a median prominent *ridge* is seen corresponding with a *sulcus* on the proximal extremity of the first phalanx. In the Hog, this ridge goes round the whole distal end of the middle metacarpals. The outer half of this distal end is a little shorter than the inner, though the difference is not, by far, so great as in Suina; and the first phalanges being modified accordingly to fit the distal extremity of the metacarpals, the outer half of the proximal surface of each is slightly higher than the inner. This corresponding inequality of the distal ends of the metapodial bones and the proximal surface of the first phalanges is seen in many fossil genera, but is most manifest in the recent Suina. The purpose of this arrangement seems to be the compression of the metacarpals of the middle digits and the approximation of their distal ends. The two middle digits diverge in treading on the ground; but, by the same action, their proximal extremities tend to converge; and, owing to the special disposition of the metacarpo-phalangeal articulation, they compress the two metacarpals or metatarsals together. In such animals as the Hog, in which this disposition is strongly developed, and aided by a special adaptation of the tarsal, and to some extent carpal, bones to bring together the proximal extremities of the two middle digits, these two practically work like the cannon of a Ruminant. In *Hyopotamus*, however, this disposition is only indicated, while it is developed much better in *Diplopus*.

The lateral digits of the *Hyopotamus* are very well developed, and, in fact, besides the *Hippopotamus*, we know of no animal in which they are so complete and relatively large as in *Hyopotamus*. It is possible that in *Anthracotherium* they took even a more important part in locomotion; but the complete limbs of *Anthracotherium* are not fully known at the present time.

The *inner or second* metacarpal (Plate XXXVII. fig. 20, & Plate XXXVIII. fig. 5, II.) is represented in all collections I have visited only by its proximal half. The upper or proximal extremity of the second digit presents an elongated and concave articular surface for the distal face of the trapezoid; its ulnar margin, as seen in fig. 5, is blunted by an oblique facet, which must have abutted against the os magnum.

On the posterior edge of this second metacarpal is a small facet, probably for the trapezium; although I did not find this last bone, its existence must be inferred from a facet on the trapezium and this posterior metacarpal facet.

The general shape of the bone is somewhat triangular; on its flat side it is pressed against the third metacarpal.

The fifth *metacarpal.*—Of this bone I have seen only somewhat less than the upper third. As shown by this small fragment, the fifth digit was relatively well developed; our fragment probably comes from a larger individual than the other metacarpals. The proximal surface has a facet which occupies its entire antero-posterior depth and articulated with the unciform (fig. 5, V.); the inner side shows two separate facets, one anterior and one posterior, which entirely correspond with similar facets on the outer side of the fourth metacarpal (the Hog and Hippopotamus has only one such facet). The outer edge of this fragment is thickened and rugose for the attachment of ligaments.

The Metacarpus of Diplopus.

The chief differences exhibited by the two middle metacarpals of the didactyle *Diplopus* (Plate XXXVIII. fig. 6) have been to a certain extent already stated in the course of the discussion of the metacarpals of *Hyopotamus*; something may, however, be added. The general shape is exceedingly different, as may be seen by the sections. The two metacarpals of the didactyle *Diplopus* are much more mutually symmetrical than those of *Hyopotamus*; the contiguous sides are flattened in such a way that the two bones are pressed together on their flat surfaces, while their outer rounded outlines sweep in and out in a nearly regular quadrant, so that the two united metacarpals represent in section the half of a solid cylinder. These inner flattened faces are very rough, showing the attachment of numerous ligaments that held them firmly together. The distal extremity is turned a little outwards and broadened transversely; its inner half is much thicker or deeper than the outer, more so than in the recent Suina. The distal articular ridge of the metacarpals is limited only to the posterior or palmar side, although a faint trace of it is visible even on the anterior face of the distal extremity of the metacarpals. The semicircular line, where the anterior surface of the metacarpal passes into the distal articulation for the first phalanx, is only slightly excavated, while in the metatarsals this line presents a deep crescentic concavity; this furnishes a very good practical character for distinguishing broken distal ends of the metacarpals from the metatarsals.

We have already mentioned the difference in the proximal surface of the third metacarpal, by the radial edge (fig. 6, III.) being more raised, by the more horizontal direction of the ulnar process, and by the depth of the excavation, into which is fitted the radial projection of the fourth digit. The posterior surface of the metacarpal is flat, as seen in the section. The fourth metacarpal (Plate XXXVIII. fig. 6, IV.) shows similar differences; the proximal surface is of a rounded triangular outline to fit the similar facet of the unciform (fig. 8′, IV.); the projection on the radial flat surface is very prominent, in order to enter into the deep pit on the ulnar side of the third and bring about a firm interlocking of the two digits. On the outer and posterior side, we see an excavation for the nodular rudiment of the fifth metacarpal, which, as it seems, did not touch the unciform, at least had no facet on it. The posterior surface is very nearly flat, and the section of the bone is a rounded triangle instead of being a flat trapezium as in the *Hyopotamus*. I have seen a complete specimen of only this single metacarpal; fortunately this gives us the length of the metacarpus in the didactyle genus; it is considerably longer than the metacarpus of *Hyopotamus*, as may be seen by comparing figs. 5 and 6 of Plate XXXVIII.

As we have no means of distinguishing with complete certainty the phalanges of the fore from those of the hind foot, they will be noticed after the description of the metatarsals.

The Metatarsals of Hyopotamus *and* Diplopus.

My materials for the hind foot are fortunately more complete than those for the fore limb, and the striking dissimilarity we noticed between *Diplopus* and *Hyopotamus* in considering the manus, is still more confirmed by the study of the pes. According to the order adopted by me, I shall describe at first the middle metatarsals, as they always exhibit the fundamental features of the pes, and consider the lateral digits afterwards. I begin with the tetradactyle *Hyopotamus*.

The *third metatarsal* (Plate XXXVIII. fig. 1, III.).—As in all Paridigitata, this metatarsal is distinguished at once by the presence, on its fibular side, of a deep pit, into which fits the corresponding projection of the tibial side of the fourth (fig. 1, IV.), giving rise to the characteristic interlocking of the middle digits. The proximal surface of the third metatarsal (fig. 2′, III.) is of a rounded triangular outline, and slightly concave to meet the slight convexity of the distal surface of the third cuneiform (fig. 1, c_3). The third metatarsal is supported entirely by the third cuneiform; and as the lateral internal (tibial) side of this third cuneiform descends a little lower than the second cuneiform, the second metatarsal going to meet its typical second cuneiform, may lean also against the third cuneiform (fig. 2, II.), a constant feature in all unreduced Ungulata. The posterior projection of the metatarsals is very long, and pressed against a similar projection of the fourth metatarsal (fig. 2′, III., IV.); on the inner (tibial) side of this projection we see no trace of a facet for the first cuneiform, such as is presented by *Diplopus* (fig. 4″, fc_1) and the recent Suina. The inner or tibial edge of the proximal surface is slightly elevated, though not enough to exclude the second metatarsal from its facet on the third cuneiform, as it may be seen also in *Hippopotamus* and *Anthracotherium*. The outer, or fibular, side of the third metatarsal is flattened (section, fig. 1) in correspondence with the adjoining side of the fourth; besides the deep pit mentioned before, we see, on this side, a long narrow facet on the posterior projection (fig. 2′), articulated to a similar facet of the posterior projection of the fourth. (As the fourth metatarsal was slightly defective in my specimen, the posterior projections of the two middle digits that must in reality articulate together are separated in the drawing.) The inner or tibial side of the third metatarsal shows an oval facet for the articulation of the second digit; a like facet is seen in the Suina and Hippopotamus, only much shorter.

The *fourth metatarsal* (Plate XXXVIII. fig. 1, IV.).—What at once strikes the observer on looking at this metatarsal, is the large projection of its tibial side, which enters into the corresponding pit of the third metatarsal; a little below it the inner surface of the bone is very rugose and bulging a little inwards. The proximal surface (fig. 2′, IV.) is slightly concave at its fore and inner part, and somewhat raised in the postero-external angle (the elevation is indicated in fig. 2′ by a deeper tint); this raised joint fits exactly into the postero-external concavity of the distal surface of the cuboid (fig. 10, IV.), while the remaining, and slightly convex, cuboidal surface is fitted to the slight concavity of the inner and fore part of the proximal surface of the fourth metatarsal.

The *outer side* of the fourth metatarsal has a lengthened oval facet for the articulation of the fifth digit; such a facet is to be seen in the Hog, only a little shorter. Whether the fifth digit articulated with the fourth by a second facet I am unable to say, as my specimen is a little defective; but very probably it did.

As the two middle digits, in their general shape, bear a great likeness to each other, all I shall say of one will be referable to the other. Their symmetry is somewhat disturbed by the slight bulging of the inner side of the fourth metatarsal; although, if we look at the anterior surface of the whole pes, this slight disturbance does not interfere with the general symmetry of the two middle digits.

The section of the middle digits (Plate XXXVIII. below, fig. 1) has a flattened trapezoid outline, especially if we take it in the upper part, where the posterior projection is prolonged downwards as a flattened platform in the upper half of the posterior surface of the metatarsals; towards the middle this platform subsides, and we have a more rectangular section. This flatness of the metatarsals is very striking in comparison with the rounded outline of the metatarsals in the didactyle genus; but one of the living Paridigitata, the Hippopotamus, has even much flatter metatarsals *, their thickness being only half of their transverse breadth. The outer margins of both middle metatarsals are made conspicuous and angular by the pressure of the completely developed lateral digits; their anterior surface is therefore very flat, even more so than in the living Hippopotamus. The middle metatarsals preserve a uniform breadth along their entire length, and we see no such conspicuous broadenings of the distal ends as in the didactyle form. The restored pes (Plate XXXVII. fig. 21) does not show this very clearly, as the complete digits from Puy were much disfigured by pressure; but it could be readily seen on some well-preserved fragments of the distal extremities. The distal end is quite smooth anteriorly, the articular ridge for the first phalanx being limited to the posterior or palmar half of the distal surface.

---

* I find in a Hippopotamus with epiphysed bones that the fourth and third metatarsal have 32 mm. transverse breadth each, and 16 and 17 mm. thickness or depth, while in *Hyopotamus* the breadth is 16 each and the depth 11 mm.

The lateral digits were completely developed in *Hyopotamus* and, no doubt, played an active part in the process of locomotion. The second metatarsal, seen from the inner side in Plate XXXVIII. fig. 2, II., is articulated to the second cuneiform by a nearly circular, flat proximal facet; this facet occupies the whole upper, somewhat attenuated, head of the second metatarsal; the anterior part of this proximal head is pressed against the third cuneiform, as seen in fig. 2, II. c_3. On its postero-tibial side, a little lower down, is seen another elongated facet, to which was articulated the first cuneiform, although this last bone was not to be found in any of the collections I visited. The shaft of the second metatarsal was closely pressed against the third, and reached very low down the metacarpus, considerably lower than in the Hog; and in my restoration of the pes (Plate XXXVII. fig. 21) the lateral digits, as I am aware now, are too much shortened. The section of the second digit is perhaps more elongated than in my figure. The distal extremity is unsymmetrical, but very well developed, the ridge for the first lateral phalanx being very high and confined to the back part of the distal end. The truncated posterior border of the proximal end of the second metatarsal is very characteristic of all Paridigitata which have retained the lateral digits: it is to be met with in the Suina, in *Cainotherium*, and even in *Hippopotamus*; this truncature is intended for the first cuneiform, which articulates with the navicular, with the posterior part of the small second cuneiform, and, by a large facet, with the truncated posterior edge of the second metatarsal *.

The *fifth* (Plate XXXVIII. fig. 1, V., Plate XXXVII. fig. 21, V.) or outer metatarsal presents, at its proximal end, a triangular facet, corresponding to the facet V. on the distal side of the cuboid (Plate XXXVIII. fig. 10); the posterior end of this fifth digit is prolonged backwards into a projection which has very nearly the same antero-posterior length as the fore or articular part. The inner or tibial side has a half reniform facet for the articulation with the fourth metatarsal. The section of this digit in the middle gives a somewhat roundish outline; its general shape is oval, the proximal third is a little curved forwards to fit more exactly the outline of the neighbouring fourth metatarsal.

The Metatarsals of Diplopus.

Of these I found several specimens in a perfect state of preservation in the collection of the British Museum †. They are all said to come from Hordwell;

---

* In *Hyopotamus*, although the third cuneiform has no regular truncated edge, as in *Hippopotamus* (Plate XXXVII. fig. 10, c_3) and *Anthracotherium*, for the articulation of the second metatarsal, still this metacarpal, owing to the fact that the second cuneiform is situated a little higher than the third, is allowed to touch this last, remaining thus true to typical relations.

† On my second visit to Puy, after this paper was written, I saw, in the collection of Mr. VINAY, a detached second metatarsal of unusually large size. It belonged to the large species, and, judging by this bone, all the four metatarsals of the larger species of *Hyopotami* were nearly subequal, as in the recent *Hippopotamus*.

and I must state that I have not seen a single specimen belonging to the didactyle *Diplopus* from Hempstead, and, *vice versâ*, not a single specimen of the tetradactyle *Hyopotamus* from Hordwell. The state of preservation of the fossils in both deposits is very different, and, as far as I can judge from information received in the British Museum, the tetradactyle genus *Hyopotamus*, identical with the genus from Puy, seems to be confined to Hempstead, while the didactyle form is found only at Hordwell *. I hope, however, to discuss the stratigraphical questions more fully at the end of my paper.

The two middle metatarsals of *Diplopus*, seemingly from the same individual, with three tarsal bones, are figured of the natural size in Plate XXXVIII. figs. 3 & 4, and two others, from a larger individual, Plate XXXV. fig. 5. The three phalanges of the fourth digit are a restoration, as I had only the corresponding phalanges from the other side; the two metatarsals are also from different individuals, and the third is a little smaller than the fourth.

The difference of these two middle digits of the pes from the corresponding bones of *Hyopotamus* is very great in general shape, section, and in some of the minor relations to the tarsal bones, the principal relations being the same in both genera.

The dissimilarity in shape is of the same order as that noticed in reference to the metacarpals. Instead of the flattened and angular metatarsals of *Hyopotamus* as seen in section Plate XXXVIII. fig. 1, we have, in *Diplopus*, very rounded, mutually symmetrical digits, which adapt themselves mutually by a large, flat inner side, and are symmetrically rounded both in and outside, so as to present in section nearly a perfect half cylinder (Plate XXXVIII. v., figs. 3, 4, 5). By this shape they differ much from the middle digits of the equally didactyle *Anoplotherium* and *Anthracotherium magnum* (the digits of which I have from Rochette, Lausanne), but present a resemblance to the same bones of the *Xiphodon* and *Entelodon* (didactyle), and also to that of the common Hog, as this last may be said to be practically didactyle. As seen in Plate XXXV. fig. 5 the distal ends are considerably broadened, and the articular ridge, though confined to the palmar side of the distal extremity, is prolonged in the form of a very low, but visible, elevation along the lower end to the anterior surface of the distal articulation (see Plate XXXVIII. fig. 6, and Plate XXXV. fig. 5). These slight peculiarities, which are too numerous to be all noticed, clearly indicate a somewhat better adaptation to didactyle locomotion, or at least some nearer approach to our recent didactyle forms than is exhibited by older forms, such as *Anoplotherium*—every new experiment of nature to produce a didactyle genus seeming to be more successful than the preceding one. However, I have no doubt the experiment ended there; and no direct connexion exists between the didactyle

---

* I have seen a *very large* lunare from Hempstead, which appears to indicate the presence of a larger *Hyopotamus* in this deposit; a very large cuboid from the same locality, though much rolled, seems to indicate, so far as can be judged by its imperfect state, the presence of another very large tetradactyle species at Hempstead. The cuboid in question presented on its distal surface two facets for the fourth and fifth digits, and no beak-like posterior projection.

Hyopotamidæ and the living genera of Paridigitates, which, as it seems to me, have descended from a branch given off by the tetradactyle Hyopotamidæ of the Eocene epoch.

The proximal articular surfaces of the two middle metatarsals of *Diplopus* (Plate XXXVIII. fig. 4″) may be compared with the corresponding proximal surfaces of the tetradactyle *Hyopotamus* (Plate XXXVIII. fig. 2′), when the differences are seen at a glance. The facet (*cb.f*) is intended to meet a like facet on the inner side of the beak-like posterior projection of the cuboid (fig. 11, *f.my*); it is wanting in *Hyopotamus*, as well as the cuneiform facet (fig. 4″, fc_1) for the first cuneiform, which was wedged in between this posterior projection of the third metatarsal and the rudiment of the *second digit* (fig. 4″, II*r*). This rudiment was confluent with the third metatarsal in one of the figured specimens (fig. 4 and 4″, II*r*), but it was absent (because not so coalesced) from all the other specimens of the third metatarsals in the British-Museum collection—for instance, from the third metatarsal represented in Plate XXXVIII. fig. 12. On the free (outer and inner) sides of both metatarsals are longitudinal facets to which the rudiments were articulated; these last, however, I could not find, save the one of the second metatarsal ankylosed to the third represented in fig. 4, Plate XXXVIII.

The interlocking of the two middle metatarsals was effected by a very prominent tubercle of the fourth entering a deep pit on the fibular side of the third, as seen in the figures; besides there is an oval facet on the inner faces of the posterior projection of each metatarsal. The beak-like downward process of the cuboid and the wedge of the first cuneiform pressing laterally from the inner and outer sides upon these posterior projections of the two middle digits held them firmly together. This close fitting of the two metatarsals (and metacarpals) together was further assisted by the mode of metatarso-phalangeal articulations universal among Paridigitata—namely, by the outer halves of the distal surface being a little shorter than the inner (as is clearly seen in Plate XXXVIII. fig. 6): in the phalanges the relation is inverse, and therefore in treading on the ground their upper ends are made to converge and to press the two metatarsals and metacarpals together; the two separate metatarsals, compressed in this way, approach as near as possible to the cannonbone of modern Ruminantia.

Phalanges.

The *first phalanges*.—In a set of mixed phalanges belonging to both *Diplopus* and *Hyopotamus* it would be utterly impossible to distinguish the bones belonging to each genus: as difficult is it to separate those of the manus from the phalanges of the pes; their relative height and thickness present no good constant characters. One of the best authorities, Professor Hensel, in his memoir on *Hipparion*, printed in the Transactions of the Berlin Academy for 1861, tells us that it is even impossible to distinguish the fore and aft phalanges of living Ungulata in the case of several individuals being mixed together. This may serve as an excuse for my not trying to do it among the fossils; and I therefore intend to give only a general description, which will apply to both the fore and hind limb.

The phalanges of *Hyopotamus* found at Puy, where the didactyle *Diplopus* is not present, are, by this fact, already separated by nature. As seen in Plate XXXVII. figs. 20 & 21, they strike us as being much longer than in most of the living genera, and considerably longer than in *Anoplotherium*. In *Xiphodon* and *Entelodon*, however, the first phalanges are also very long.

The upper, or proximal, articular surface is not symmetrical, as the inner side of the first phalanx is considerably thicker than the outer, in correspondence with the same inequality of the distal extremities of the metacarpal and metatarsal bones. The same difference in the thickness of the inner side is also to be seen on the distal extremity. The proximal surface is concave, and the groove for the articular ridge of the metacarpal is limited to its posterior third only. This thickening of the inner side makes also the inferior end not completely symmetrical; and this want of symmetry is much greater in the first phalanges of the didactyle *Diplopus*.

The *second phalanges*.—The second phalanges of all Paridigitata (with the exception of *Hippopotamus* and *Camelidæ*) are very characteristic, as their distal extremity is shaped unsymmetrically in a peculiar manner, so as to cause the ungual phalanges to converge in treading on the ground. For this purpose, the outer half of the distal articular surface is not only much larger than the inner, but bends obliquely inwards, and the ungual phalanges following this inner curve tend to converge. This arrangement is very strongly developed in the second phalanges of *Anoplotherium* (see De Blainville, Ostéogr. *Anoploth.* pl. iii.); it may be seen in every Ruminant as well as in the Suidæ. *Hyopotamus* and *Diplopus* also have second phalanges shaped on this pattern; only this want of symmetry is not so clearly developed as in the Suina or Ruminantia.

The *third phalanges*.—These have a very peculiar shape and are quite identical in both genera. This strange shape I can compare to nothing better than to a very thickened and rounded human nail. Their proximal surfaces are unsymmetrical, to fit the unsymmetrical distal end of the second phalanges; but the remaining part is much more symmetrical than in the Suina or Ruminantia, the inner side not being flattened at all, or very slightly. The palmar surface is quite flat. The lower and anterior margin shows the usual vascular foramina and a certain crispness to allow a firmer fitting of the horny hoof.

With this I conclude my description of the long bones of the skeleton and the bones of the limbs; the latter are all figured of the natural size, and the sections give a correct idea of their breadth and antero-posterior depth. Some exact dimensions which could be taken are given in the general Table (p. 90) I have taken the liberty of disposing right and left as best suited my purpose; and while some bones from the collection of the British Museum were drawn directly from nature, and therefore in the Plates appear to belong to the opposite side, others have been reversed.

Table of Measurements of the Extremities *.

	Hyopotamus.				*Diplopus.*	
	Puy.		Hempstead.		Hordwell.	
METACARPALS.	III.	IV.	III.	IV.	III.	IV.
Length	105	....	....	....	....	138
Transverse breadth, proximal face	17	16½	17	16	19	20
,, ,, middle	16	15½	....	15	....	18
,, ,, distal extremity	20	....	....	....	....	22
Antero-posterior depth in the middle	10½	....	10	10	14	16
METATARSALS.						
Length	113	....	....	....	140	156
Transverse breadth, proximal face	18	18	....	14, 13	18, 15	22, 18
,, ,, middle	16	16½	....	9, 10	15, 14	16, 17
,, ,, distal extremity	....	....	....	....	20	24½
Antero-posterior depth in the middle	11	10	....	....	16, 15	17, 16
FIRST PHALANGES.						
Length	48, 49, 50		37, 38, 40		51	
Transverse breadth, proximal face	21, 21, 22		16, 16, 17		25	
,, ,, distal extremity	15, 16, 16½		13		17½	
SECOND PHALANGES.						
Length	25, 24		....		25, 30	
Transverse breadth, proximal face	16, 15½		....		18, 19	
,, ,, distal extremity	14, 13½		....		16, 17	
THIRD PHALANGES.						
Length	27, 28		....		29	
Transverse breadth, proximal face	14, 14½		....		15	

EXPLANATION OF THE PLATES.

PLATE XXXV.

Fig. 1. Scapula of *Diplopus*, Hordwell, ⅔ nat. size. Brit. Mus.
a, acromion; *cp*, coracoid process.

Fig. 2. Distal extremity of the femur of *Hyopotamus*, Hempstead. Mus. Pract. Geology.
it, internal trochlea.

Fig. 3. Extremity of the fibula of *Diplopus*, nat. size, Hordwell. B.M.

Fig. 4. Calcaneum of *Diplopus*, Hordwell. B.M.
ff, fibular facet; *as*, astragalean facet; *cb*, cuboid facet.

---

* The absence of a number indicates that the bone was broken at that particular place and did not allow of exact measurement. My materials for the lateral digits were much more scarce than for the middle ones, as the former, through their slenderness, are often broken and lost. Nearly all the bones of *Hyopotamus* figured, from Puy and Hempstead, belong to the small species *Hyopotamus velaunus*, Aym. Such measurements as I could take of the lateral digits show that they have half the breadth of the middle ones. So the breadth of the second metacarpal from Puy is 8 millims., the depth 10 millims.; the second metatarsal is 8½ millims. broad, and 6 deep at the attenuated proximal end; the fifth metacarpal is 9½ millims. broad and 8 millims. deep at the proximal end; the fifth metatarsal is 9½ millims. broad and 9 millims. deep.

Fig. 4′. Calcaneum of a Perissodactyle (*Anchitherium*).
i, internal astr. facet; *e*, external astrag. facet; *s*, sulcus sustentaculi.
Fig. 5. Two metatarsals of *Diplopus*, left foot, from the New Forest (Brockenhurst). B.M. The phalanges of the third digit are restored.
Fig. 5′. Section of these two metatarsals in the middle.

All the figures except the scapula are of the natural size.

PLATE XXXVI.

Figs. 2 & 3 are of the natural size, all others two thirds of the natural size.

Fig. 1, side, and fig. 1′, front view of the ulna of *Diplopus* from Hordwell. B.M.
or, outer radial facet; *ir*, internal radial facet.
Fig. 2. Front view of the upper part of the ulna of *Hyopotamus*, Puy: *or*, external radial facet; *ir*, internal radial facet; *cb*, connecting bridge.
Figs. 1″ & 2′. Sections of both ulnæ: *e*, external; *i*, internal edge; *a*, anterior; *p*, posterior surface.
Fig. 3. Proximal part of radius of *Hyopotamus*, Hempstead. B.M.
Fig. 3′. Distal extremity of the radius of *Hyopotamus* from Hempstead.
ex, external; *i*, internal side, B.M.
Fig. 4. Humerus of *Diplopus*, from Hordwell. B.M.
c, intercondylar perforation; *a*, middle bulging; *b*, internal projection.
Fig. 4′. Section of the same.
Fig. 5. Femur of *Hyopotamus* from Puy.
t.mj, trochanter major; *t.mn*, trochanter minor.
Fig. 6. Smaller femur from Hempstead. B.M.
Fig. 7. Tibia and fibula of *Diplopus*, Hordwell. B.M.
Fig. 7′. Distal view with the fibula. Fig. 7″. Section about the middle of the bone.

PLATE XXXVII.

Letters common to all the figures:—*s*, scaphoid; *l*, lunar; *p*, pyramidal; *tz*, trapezium; *t*, trapezoid; *m*, os magnum; *u*, unciform; *c*, calcaneum; *a*, astragalus; *n*, navicular; *cb*, cuboid; c_3, third, c_2, second, and c_1, first cuneiform.
Fig. 1. Right fore foot of *Hippopotamus*; fig. 2 of *Anoplotherium tridactylum* from Vaucluse; fig. 3 of *Xiphodon*.
Fig. 4. Side view of the right fore foot of the Hog; fig. 5 of *Dicotyles*; fig. 7 of *Tragulus Kantchil*; fig. 8 of *Hyomoschus aquaticus*.
Fig. 6. Third right metacarpal of *Palæochœrus* (Allier), to show the absence of the radial enlargement.

Fig. 9. Right hind foot of *Hippopotamus*. Fig. 10. Side view of the same, to show the articulation of the third and second metatarsals with the first, second, and third cuneiforms.

Fig. 11. Left hind foot of *Anoplotherium tridactylum.*

Fig. 12. Side view of the right hind foot of the Hog; articulation of the third and second metatarsals with the three cuneiforms. Fig. 12′. Third metatarsal of *Palæochœrus*. Fig. 13. *Dicotyles*. Fig. 14. *Hyomoschus aquaticus*. Fig. 15. *Tragulus Kantchil*. Fig. 16. *Amphitragulus* (?) from Allier.

Fig. 17. Distal surface of the navicular of *Anoplotherium commune*, Paris gypsum, to show the facets for the three cuneiforms.

Fig. 18. The same bone from Vaucluse. Fig. 19. The same bone, *Anoplotherium tridactylum*, to show the great development of the facet for the second cuneiform (c^2), which carries the second digit.

Fig. 20. Fore foot of *Hyopotamus* from Puy (partly restored).

Fig. 21. Hind foot of the same.

Figs. 1, 9, and 10, $\frac{1}{5}$ nat. size; figs. 2, 11, 20, and 21, $\frac{1}{2}$ nat. size; all others of the natural size.

PLATE XXXVIII.

Same letters as in Plate XXXVII.

Fig. 1. Hind foot of *Hyopotamus*, Puy.

as, astragalean; *cl*, calcaneal facet of the cuboid.

Fig. 2. Same, side view. The third and second cuneiforms are coalesced; the first cuneiform is absent.

Below fig. 2, proximal faces of the four metatarsals and section of the same.

Fig. 3. Hind foot of *Diplopus*, Hordwell. B.M.

Fig. 4. Side view of the same.

b.cb, beak of the cuboid; fc_1, facet for the first cuneiform; II*r*, rudiment of the second metatarsal coalesced with the third.

Fig. 4′. Section of the two middle metatarsals at half their length.

Fig. 4″. Proximal view of the metatarsus of *Diplopus*.

cb.f, facet for the descending beak of the cuboid; fc_1, facet for the first cuneiform; II*r*, rudiment of the second metatarsal coalesced with the third.

Outline of the distal face of the two coalesced cuneiforms (third and second) of *Diplopus*, fitting the proximal face of the third metatarsal with the coalesced rudiment of the second metatarsal (II*r*). B.M.

Fig. 5. Fore foot of *Hyopotamus*, Puy.

Fig. 6. Two metacarpals of the fore foot of *Diplopus*, Hordwell. B.M.

Fig. 7. Distal view of the unciform of *Hyopotamus* from Puy.
III, IV, V, facets for the corresponding metacarpals.

Figs. 8 & 8′. Front and distal view of the unciform of *Diplopus*, Hordwell. Mus. Cambridge.
ln, lunar facet; *py*, pyramidal facet; III, V, facets for the two metacarpals.

Fig. 9. An unciform of *Hyopotamus* from Hempstead. Fig. 9′. Distal view of the same. Smaller than the unciform from Puy. B.M.

Fig. 10. Distal view of the cuboid of *Hyopotamus*, Puy.
tr, transverse ridge; IV, V, facets for the two corresponding metatarsals.

Fig. 11. Distal view of the cuboid of *Diplopus*. B.M.
f.my, facet for the fourth metatarsal on the posterior beak; IV, facet for the single fourth metatarsal.

Fig. 12. Another third metatarsal of *Diplopus*, without the rudiment of the second.

All the hind feet are right; the fore foot is left.

PLATE XXXIX.

Fig. 1. Cranium of the largest species of *Hyopotamus*, from Puy. Two thirds nat. size.

Fig. 2. Side view of the head of a smaller *Hyopotamus*, from Puy. Nat. size.

Fig. 3. Lower jaw of the same; said to come from the same block.

Fig. 3′. Upper view of the anterior extremity of the lower jaw.

Fig. 4. One molar (m^1) and three milk-molars of *Hyopotamus*, Puy.

Fig. 5. Part of the head, from the postglenoid process to the occipital condyle.

Fig. 6. Dorsal vertebra of *Hyopotamus*.

Fig. 7. Second cervical vertebra of *Hyopotamus*, from Puy. Collection Pichot.

Fig. 8. Left lower molar of *Chalicotherium*. Fig. 9. *Anoplotherium*. Fig. 10. *Dichobune bavarica*, Fraas. Fig. 11. *Hyopotamus*. Fig. 12. Ruminant from Allier.
ac, anterior crescent; *pc*, posterior crescent; *ap*, anterior pillar; *pp*, posterior pillar.

Fig. 13. Left upper molar of *Rhagatherium*; fig. 14 of *Hyopotamus Gresslyi*. Fig. 15. Intermediate form between the *Hyopotamus* and *Dichodon*; the anterior middle (fifth) lobe is coalesced with the internal. Fig. 16. *Dichodon*, from Mauremont.
el, external anterior lobe; *ml*, middle anterior lobe; *il*, internal anterior lobe.
The teeth (figs. 13, 14, 15) have the three lobes on the fore part of the tooth.

Fig. 17. Left upper molar of *Dichobune leporina*, Cuv.; and fig. 18 of *Cainotherium*: the three lobes are on the posterior part of the tooth.

Fig. 18. The so-called *Cainotherium* (*Hyopotamus*) *Renevieri*, Pict., having, like all the other *Hyopotamidæ*, the three lobes on the anterior part of the tooth.

PLATE XL.

Fig. 1. Head of *Hyopotamus velaunus*, Aym., from Puy; restored, but belonging to one individual: all the pieces were found together in the same block. Side view.

Fig. 2. View from above, to show the great sagittal crista.

Fig. 3. Lower jaw of a very young *Hyopotamus* from Puy; the first molar is concealed in the jaw.

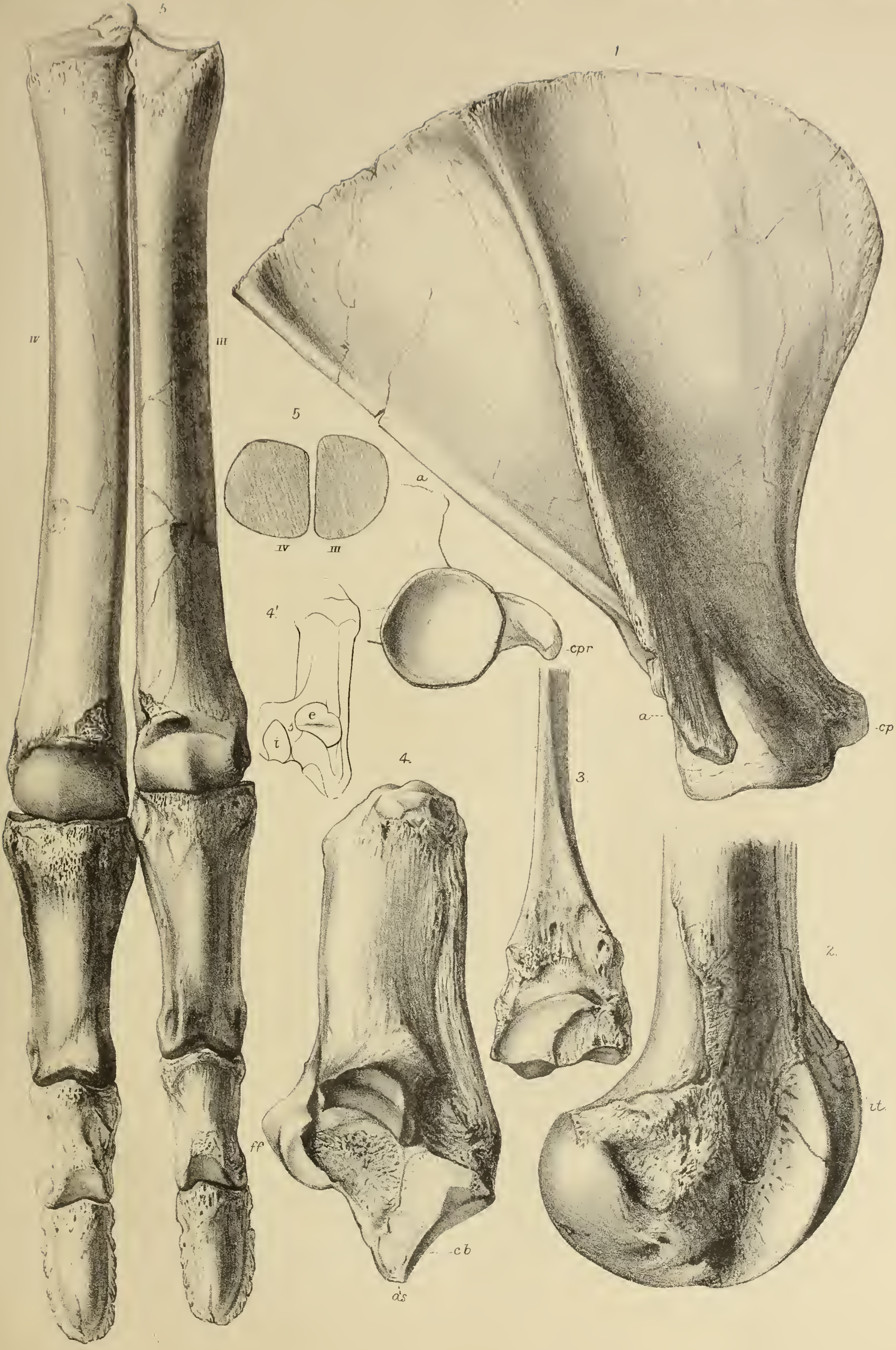
d^1, d^2, d^3, the three milk-molars; p^4, the first premolar which has no milk-tooth to precede it.

Fig. 4. Upper view of the three milk-molars.

LIBRARY OF THE UNIVERSITY OF ILLINOIS

Kowalevsky.

Phil. Tran. MDCCCLXXIII. Plate [illegible]



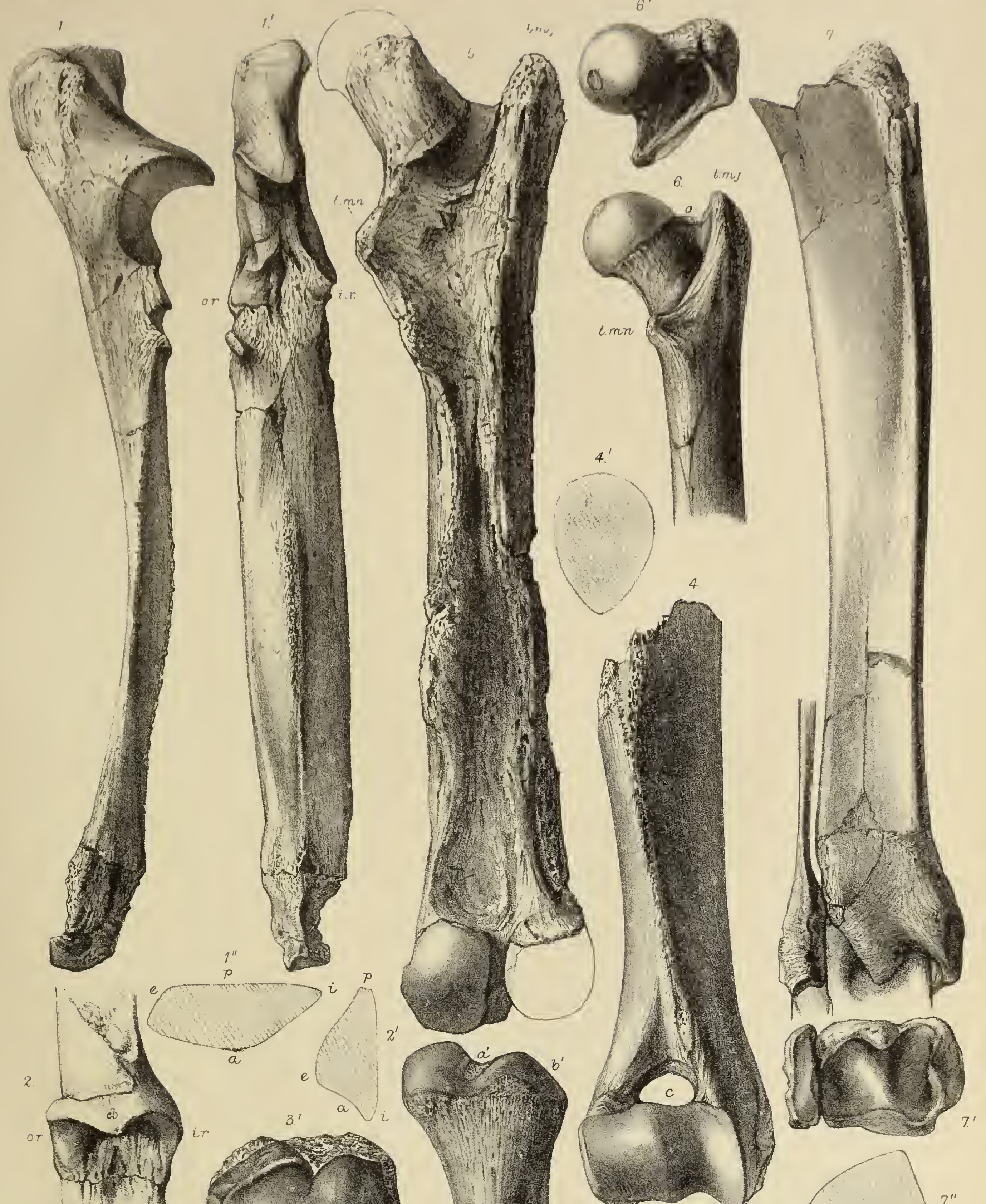
C. L. Griesbach lith.

Mintern Bros imp.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

Kowalevsky

Phil. Trans MDCCCLXXIII Plate [illegible]

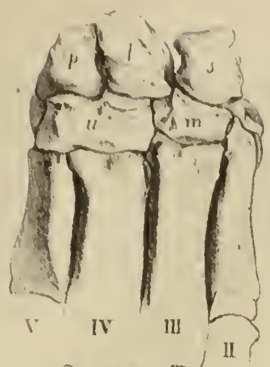


C.L. Griesbach lith.

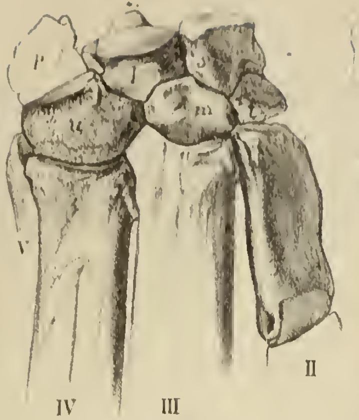
Mintern Bros. imp.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

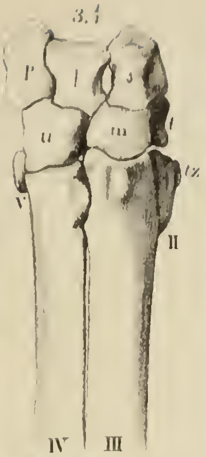
1.½



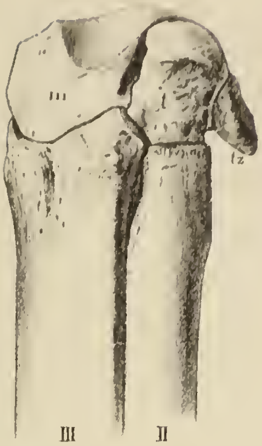
2.¹



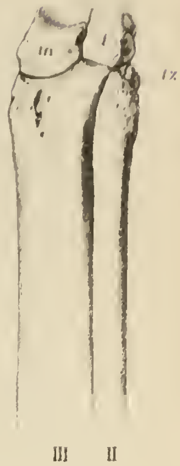
3.½



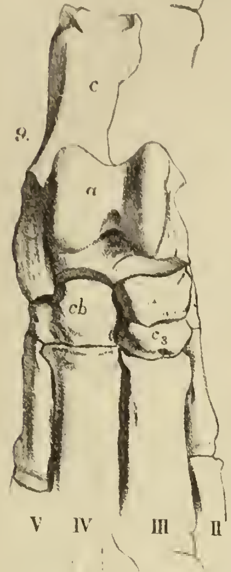
4.½



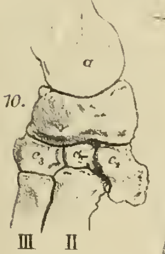
5.½



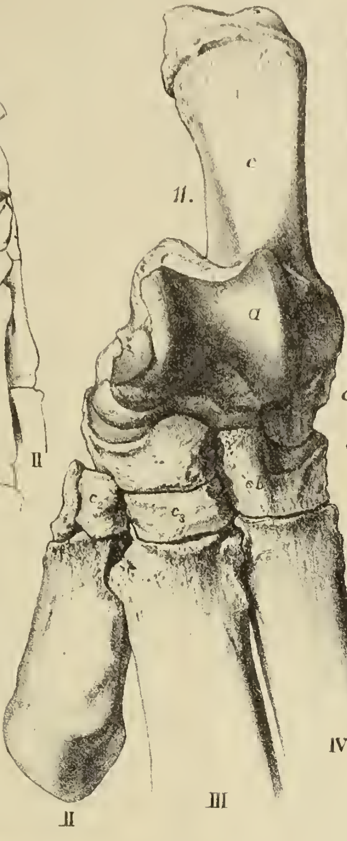
9.



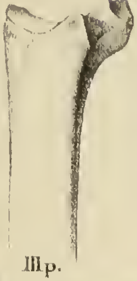
10.



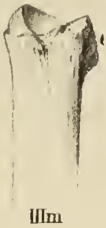
11.



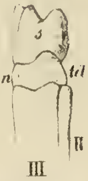
12.



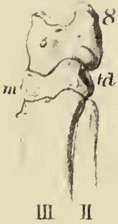
6.



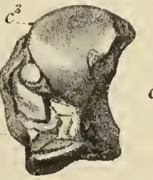
7.



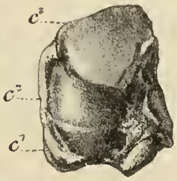
8.



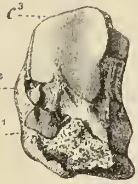
18.



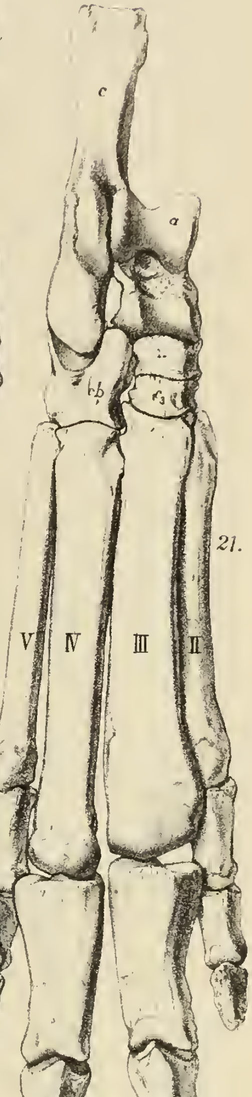
19.



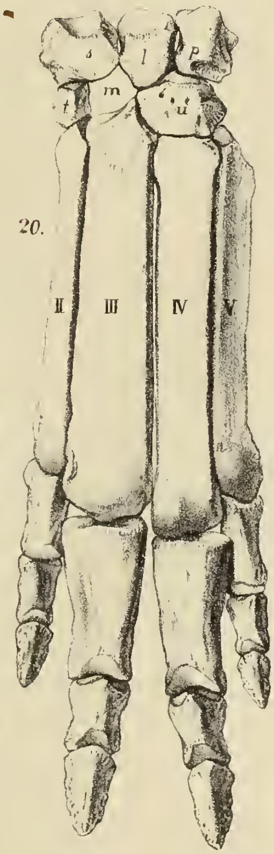
17.



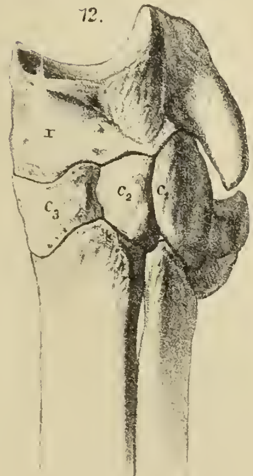
21.



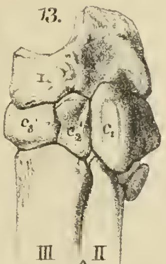
20.



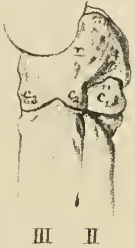
12.



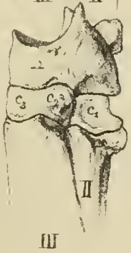
13.



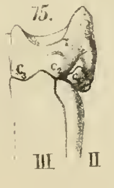
14.



16.



15.

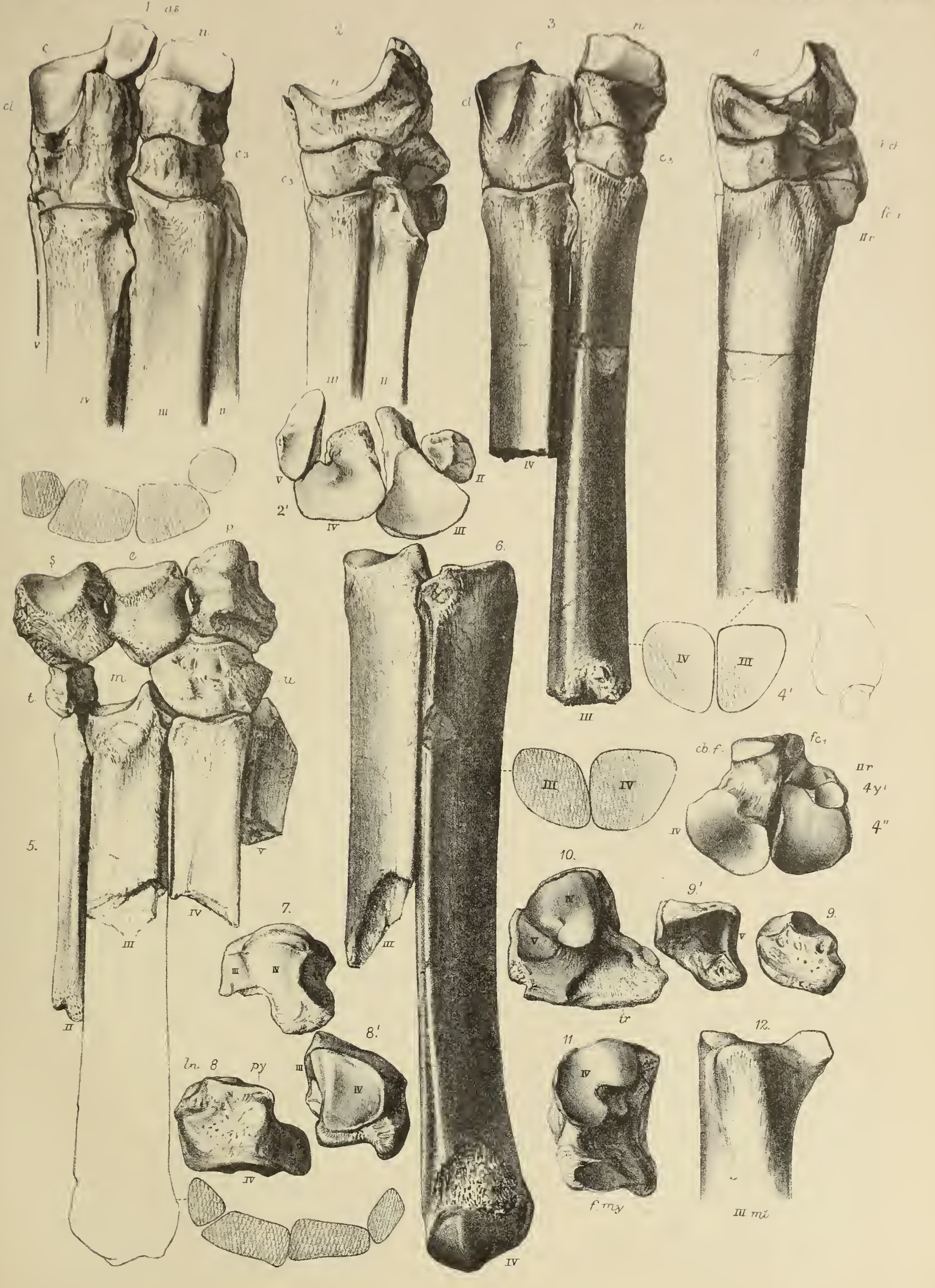


C. L. Griesbach del. et lith.

Mintern Bros. imp.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

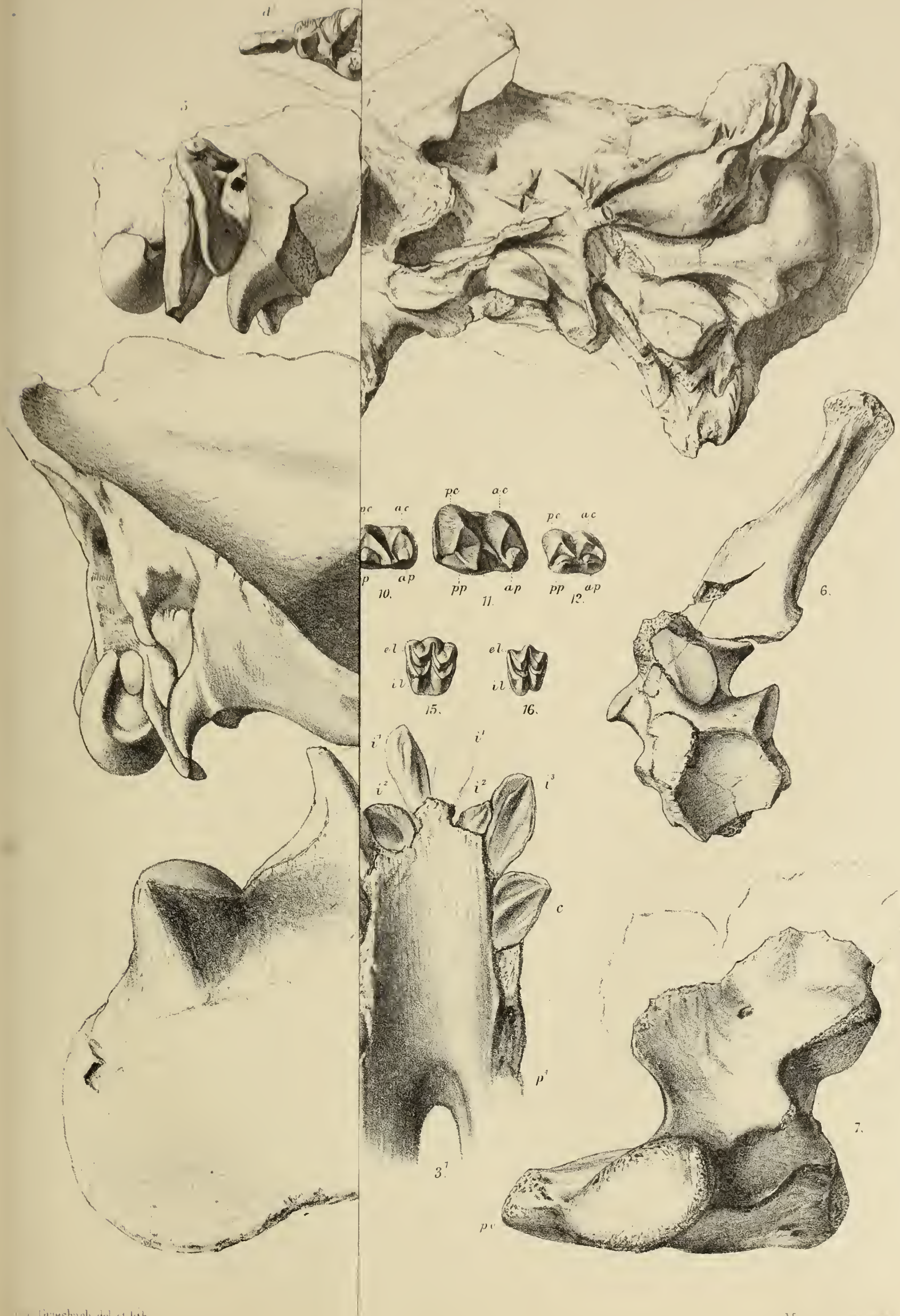
Kowalevsky.



C.L. Griesbach lith.

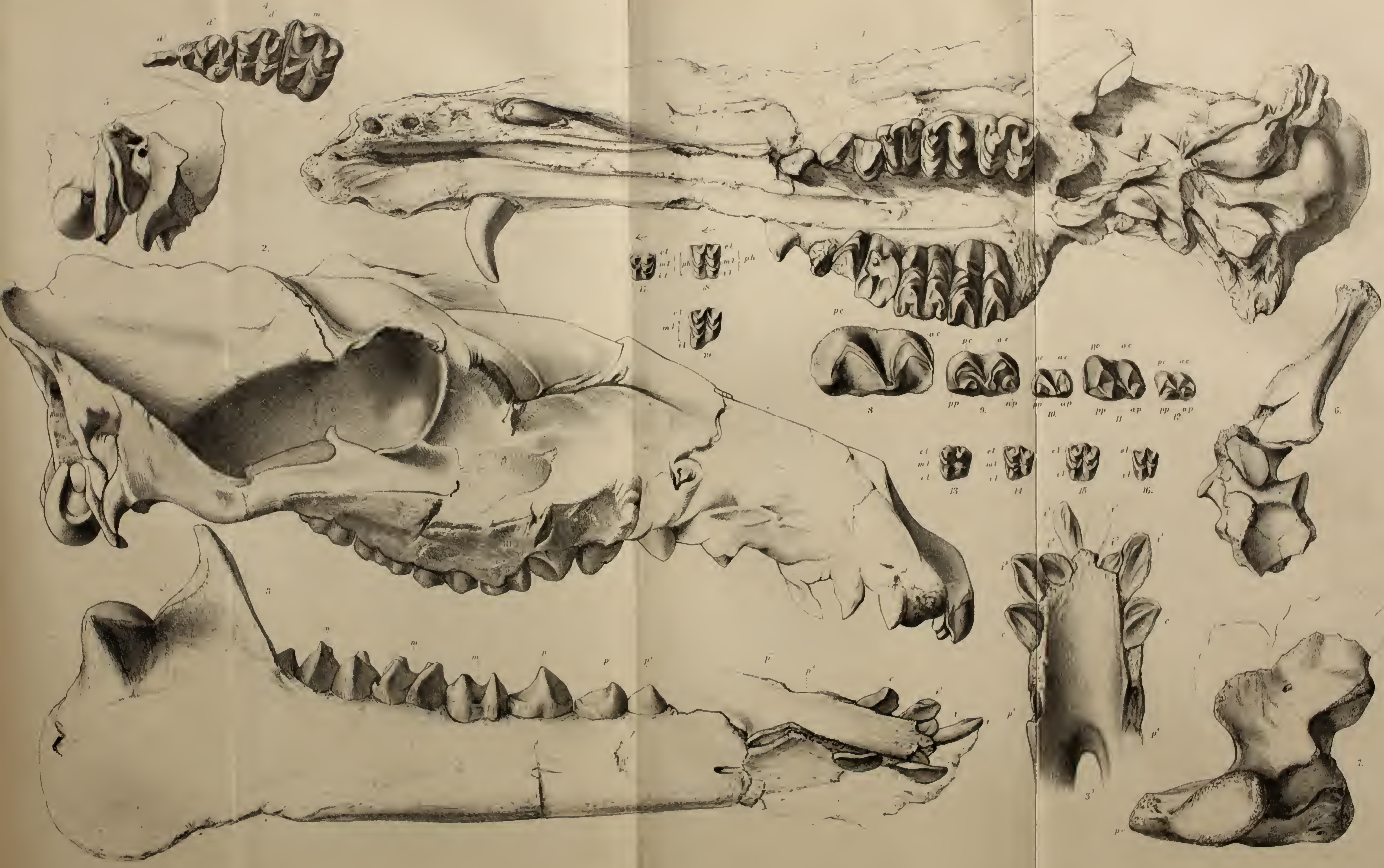
Mintern Bros imp.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS



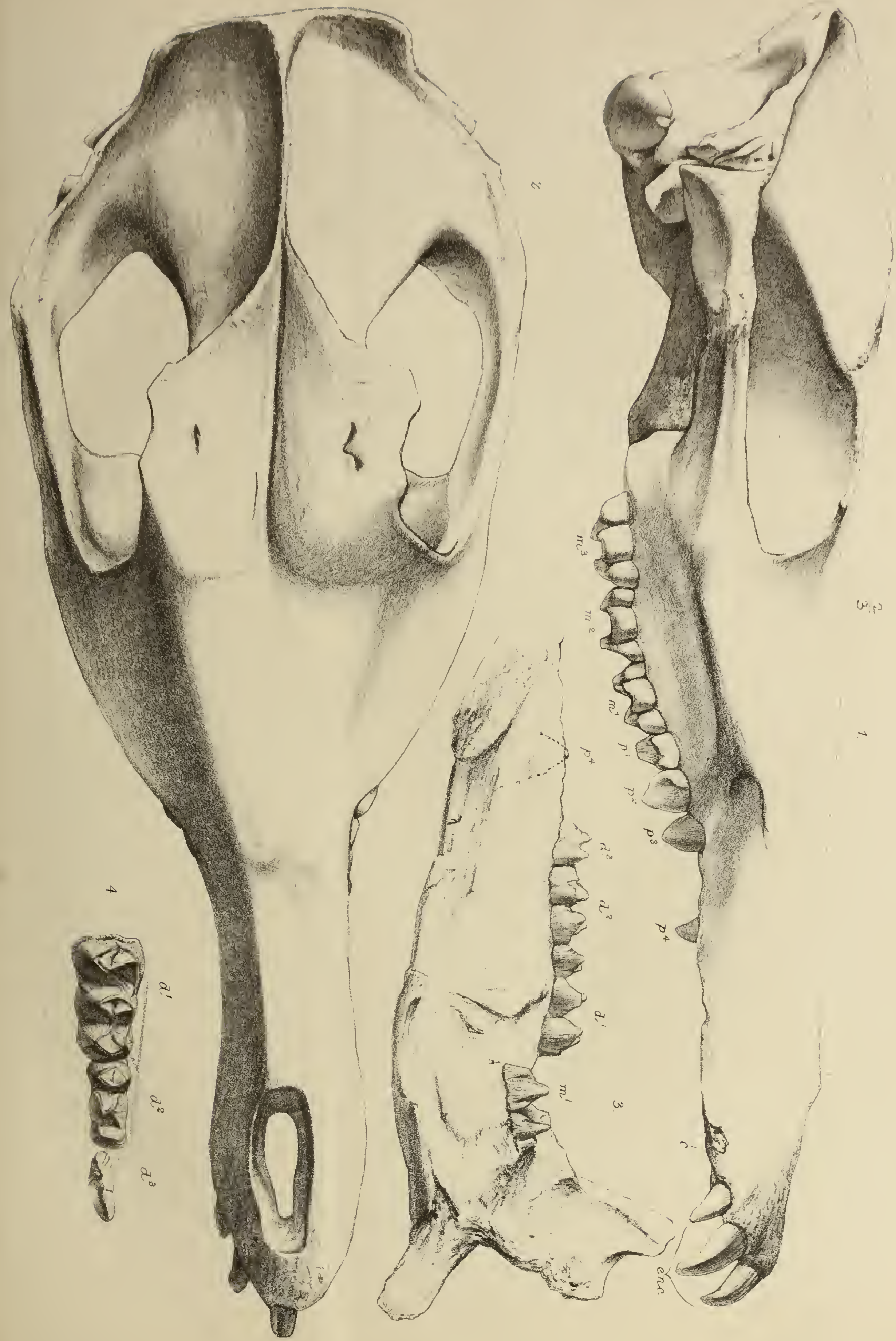
Griesbach del et lith

Mintern Bros. imp.


1
2
3
3'
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
d
d'
m
m'
p
p'
p²
c
i
i'
i²
i³
pc
ac
pp
ap
el
ml
il
ph

[illegible] del. et lith

M[illegible]



G.L. Griesbach lith.
Mintern Bros imp.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

II. THE BAKERIAN LECTURE.—*On the Structure and Development of the Skull in the Salmon* (Salmo salar, *L.*). *By* WILLIAM KITCHEN PARKER, *F.R.S.*

Received April 18,—Read May 30, 1872.

Introductory Remarks.

AT the close of my last communication, on the Frog's Skull, I promised to bring forward a paper on that of the Salmon; indeed the present paper should have appeared next after my memoir on the Skull of the Fowl (see Phil. Trans. 1869, p. 804); but the invaluable labours of my friend Professor HUXLEY on the "face" of the Vertebrata (see Proc. Zool. Soc. 1869, pp. 391–407) deflected me for the time, and I was led to labour at the Amphibia. This new subject has been fraught with as much pleasure as the one before it; for although the Salmon begins as a *higher type* and ends as a *lower* than the Frog, yet it also undergoes no little metamorphosis, and its transformations are not a whit less instructive than those of the Frog. Moreover, let this be said in praise of this fish, that its eggs and its fry are the most exquisite objects the morphological observer can ever hope to spend his time upon—their size and their diaphanous character making them excellent subjects for section, dissection, and viewing under any and every degree of magnifying-power. As to the source of these specimens, it is due to the donors that their names should be mentioned here; they are my friends Messrs. B. WATERHOUSE HAWKINS, FRANK BUCKLAND, and HENRY LEE, who have most kindly put every valuable specimen into my hands that I have desired, not only for this paper, but for others completed, in hand, or in prospect.

CUVIER must be taken as the great pioneer in this branch of Ichthyotomy; many of his determinations are excellent, yet, from his not having worked out the development of the Fish, several of his terms are not defensible.

My own earlier study of the Fish's skull was assisted by Professor OWEN'S well-known 'Lectures on the Vertebrata' (vol. ii.); his modification of the Cuvierian nomenclature is very elegant and useful. Of course the determination of homologies will differ largely when one worker looks at them from the transcendental stand-point, whilst another creeps up to them from below, caring only to see them in the light of development: my divergence from this "guide" was soon to take place.

Professor HUXLEY'S Croonian Lecture, delivered before the Royal Society on June the 17th, 1858, gave a painful but healthy shock to my mind; having learned that the whole subject had been begun from the wrong end, it took some time to acquire calmness and courage to begin afresh. Help, however, came in time; and the same author threw much new light upon this difficult subject in his Hunterian Lectures, delivered at the Royal College of Surgeons of England in 1863.

During that time, and since then, this subject has been frequently and warmly discussed between Professor Huxley and myself; although all that I have written hitherto upon Ichthyotomy has been incidental and in elucidation of higher types, yet, with the exception of the Bird-class, the Fishes have received most of my attention.

In the present paper the nomenclature will be based upon Cuvier's, as modified and made elegant by Owen and as corrected by Huxley. I shall, however, have to differ on several points from the last of these three anatomists.

The most invaluable part of Professor Huxley's labours is that which has given us the true auditory elements in the bony skeleton; three of these are almost universal—namely, the "prootic," the "opisthotic," and the "epiotic." Cuvier only recognized the second of these as necessary to the "pars petrosa," his "rocher;" the prootic was mistaken by him for the "great wing of the sphenoid," and the epiotic as part of the occipital arch, his "external occipital." But Cuvier, and Owen after him, were right in putting another element, their "mastoid," amongst the auditory centres; and Professor Huxley was wrong in supposing this piece to be the "squamosal." I pointed out this error to him before his Lectures were in print; but he was doubtful about what I had long felt certain of, and called it my *opinion* (see note to p. 188 in his Elem. Comp. Anat.). In his new work, however ('Anatomy of the Vertebrated Animals,' 1871, p. 153), this bone is put into its proper category: thus we have *four* "periotic" bony centres. I now have to speak of another periotic bone, the nature of which I have long pondered over, namely the "postfrontal." This bone, which was so called by Cuvier, but has nothing in common with his Reptilian postfrontal (a mere postorbital investing plate), begins as a delicate tract of osteoblasts immediately outside the ampulla of the anterior semicircular canal; another ossifying tract begins over the ampulla and arch of the horizontal canal, this is the "pterotic;" a third over the ampulla of the posterior canal, this is the "opisthotic;" a fourth over the arch of that canal, the "epiotic;" whilst the fore edge of the periotic capsule is ossified by the "prootic." I thus anticipate my descriptions for the sake of starting fair in my terminology; I propose the term "sphenotic" for the antero-superior or postfrontal bony centre.

As soon as possible all the terms must be put into harmony with the facts of morphology, and terms that are applied to two different parts in different Classes must be got rid of if they can conveniently be spared. Thus the term prefrontal, which is applied to a mere investing bone in one case and to the lateral mass of the ethmoid in another, ought to give way, in one case to preorbital, and in the other to a true morphological term, namely "ecto-ethmoid."

I have long ceased to use such terms as "os transversum," "ectopterygoid," and "entopterygoid," as they do not mean the same thing in the Fish as in the "Sauropsida" and the Mammalia. Cuvier's "transverse" of the Fish is really the pterygoid, as Professor Owen has well shown: Professor Huxley calls it "ectopterygoid;" whilst his entopterygoid (the Owenian name in this case, and answering to the internal "pterygoid" of CUVIER) does not answer to the internal pterygoid plate of Man and the other Mammalia, but to an additional bone occasionally seen even in them. By adopting the term "transpalatine" for the Reptilian transverse bone, "pterygoid" for the homologue of our internal pterygoid plate, and "mesopterygoid" for the innermost or submesial plate, I seem to myself to have struggled out of a quagmire of obstructive terms on to something like a raised causeway.

Many specially ichthyotomical terms must be retained, such as "hyomandibular," "symplectic," and the like; for although we now begin to see what the representatives of these bars are transformed into in the higher classes, yet they have in their more primitive condition in the Fish an essentially specific character as morphological elements; whilst their metamorphosed counterparts in the higher types may be compared to new species, developed during secular periods.

In my last paper I stated my opinion as to the merely *varietal* value of the bony deposits that take place in the general connective web; these bony plates may be *superficial*, *intermediate*, or *deep*, the latter mostly fastening themselves on to cartilaginous tracts, and causing their transformation into true bone.

We have three groups of such bones—namely, "dermostoses," "parostoses," and "ectostoses:" in the Teleostei, as a rule, there are no "endosteal" deposits, or direct calcification of cartilage-cells, such as we see in Sharks, Rays, and in the "Anoura;" in the Salmon there are no "dermostoses" nor "endostoses."

If the reader will refer to the figures of *Callichthys* (a Teleostean covered with Ganoid armour) in my memoir 'On the Shoulder-girdle,' he will see how gently and almost insensibly the body-plates pass into the armour for the head; this is the first degree of specialization in relation to the cephalic endoskeleton. A further degree is obtained by the ossific deposit being found in a deeper stratum, the skin itself becoming the seat of deposits that form the proper scales of the fish, unrelated to the cartilage beneath; this we see in most Teleostei.

Let this be held in mind, and then all those bony plates in the Salmon's head which do not engraft themselves upon the cartilaginous skull and face can be arranged into one category—the splints, or "parostoses."

The deeper strata of bony deposit, on account of their peculiar behaviour correlative to the endoskeleton as "ectosteal" laminæ, are, as it were, taken into the very body and substance of the endoskeleton, and become part and parcel of it; they may be called *secondary endoskeletal elements*, in contradistinction to the parts into which they grow, which are *primary*.

Thus in morphological species, as well as zoological, there is frequently a dovetailing of members, a mutual trespassing of territories; and the sharp boundaries, which for the sake of logical clearness we are always drawing out, often belong to us, as intellectual conceptions, rather than to Nature, as solid and tangible facts.

Before concluding these remarks I must express my gratitude to Dr. TRAQUAIR for his excellent paper on the *Polypterus* ('Journal of Anatomy and Physiology,' vol. v.); it has helped me greatly, beautifully showing the meaning of the earlier "Ganoid" stage of the Salmon's skull.

Structure of the Adult Salmon's Skull.—Eighth Stage.

I begin with the adult, and this because of the multiplicity of parts in the Teleostean skull: he has mastered no easy piece of work who knows these parts and their relations.

On the upper surface of the Salmon's skull there are five important parastoses—namely, the "superethmoidal," the frontals, and the parietals (Plate VII. fig. 1, *eth.*, *f.*, *p.*).

The parietals (*p.*) are small, ridged, subarcuate bones, separated by the whole width of the broad supraoccipital (*s.o.*); they articulate with it, and also with the corresponding frontal (*f.*) and with the epiotic (*ep.*); their relation to the ossified and unossified skull proper is shown in section (Plate VIII. fig. 6, *p.*, *s.o.*).

The frontals (*f.*) are, as is usual in the Teleostei, very large; they only meet to form the sagittal suture in their hinder half, for further forwards the smooth strong ridge of the cartilaginous skull separates them. They rise thin towards the edge, and at the base of this ascending lamina there is a considerable sulcus, outside of which they expand to an equal size again in front, and to twice the width behind. The fore and outer part is leafy and jagged, so is the hinder half at its extreme width, in its supraorbital portion; but the rest is a thick bed of excavations for fatty tissue. The exact relation of the frontals to the skull proper is shown in a series of transverse sections (Plate VII. figs. 8–11, and Plate VIII. figs. 4 & 5, *f.*).

The character of the frontal roofing is well shown by the effect produced and the parts exposed when these bones are removed (compare Plate VII. fig. 1 with Plate VIII. fig. 1).

The fore part of the cartilaginous skull is covered in by a bone (Plate VII. fig. 1, *eth.*) which has been the subject of much discussion; and here the Salmon shows itself to be a halfway type between the typical Teleostei and the Ganoids.

In the "Siluroids," for instance *Callichthys* and *Clarias* (see for the latter, Huxley, Mem. of Geol. Surv. decade 10th, 1861, p. 30, fig. 20, *eth.*), there is a large Ganoid scale in this region, similar to what is found in *Coccosteus* (*op. cit.* p. 30, fig. 19, *eth.*). Now in the "Siluroids" the dermal scute has coalesced with a true meso-ethmoidal bone, formed by an ectostosis; but in the Salmon that region of the skull is entirely unossified, and the bony plate is parosteal. In another malacopterous fish, the Pike (*Esox lucius*), there are two ossifications in the meso-ethmoidal cartilage, one on each side in front (see Huxley, 'Elem.' p. 186, figs. 7. 3, A, B, C 3), and the long, flat snout is overlain by a pair of parostoses (*op. cit.* p. 168, fig. 69. 2). Then in other Malacopteri, namely, the "Cyprinoids," there is a proper median ossification of the meso-ethmoidal cartilage (see Huxley, Croon. Lect. p. 24, fig. 6, *eth.*); and this is the state of things in the "Acanthopteri" (e. g. *Zeus*) and the "Anacanthini (e. g. *Gadus*). In the "Ganoid" *Polypterus*, the median, proper meso-ethmoidal bone is invested by a pair of large ganoid plates (TRAQUAIR, Journ. Anat. and Phys. vol. v. figs. 1, 2, 3, 7, *na.*); these are supplemented by an additional pair (*na'.*). The nasal sac itself has a small roof-bone, lettered *o.t.* (*os terminale*) in Dr. TRAQUAIR'S figure. In MÜLLER'S figure of *Polypterus*, as quoted by HUXLEY, *op. cit.* p. 22, the main superethmoidal plates are lettered *N.* It is evident, therefore, that there are several candidates in the *Polypterus* for homology with the human nasal bones. In the Fishes generally I retain the term "nasal" for the "os terminale" (the so-called "turbinal" of OWEN), which is the foremost of the upper fork of the "lateral-line" series of mucous bones, and which covers the nasal sac. This bone is shown in the Salmon in Plate VI. fig. 1, *n.*; it belongs to the same category as the superorbital (*s.o.b.*). These investments of the nasal region have merely to be regarded as a commencing specialization of the dermal scutes in relation to more and more metamorphosed ethmoidal structures.

Two large splints, one very large, invest the basis cranii; one of these has been known for many centuries in its mammalian form; it is the vomer (Plate VII. fig. 2, *v.*). This is an oblong bar of bone, thick in front; it sends upwards a sharp keel on this anterior portion, between the halves of the ethmoid (Plate VII. fig. 5, *v.*); behind, it is carinate downwards (Plate VII. fig. 7), and it is armed with sharp recurved teeth. This bone underlies the next for a considerable distance (Plate VII. figs. 2, 7, 8, *v.*, *pa.s.*). The next bone, by its primordial condition, characterizes the Ganoid and Teleostean Fishes and the Amphibia, although I find few even of the higher Vertebrata without traces of it; it is largest in the lower Ganoids, for instance the Sturgeon. A good Ichthyopsidan name was first given to it, "parasphenoid," by Professor HUXLEY (see Elem. p. 170); it is a submucous bone, intimately related to the basis cranii, and is of great length (see Plate VII. figs. 2 & 4, *pa.s*). This bone is large, a long leaf, with descending laminæ, and is split in front. It is also split behind into several snags, and from its hinder third sends upwards "basitemporal wings." It is upwardly keeled in front, downwardly keeled behind, and flattened in the middle (see sections, Plate VII. fig. 7–11, & Plate VIII. figs. 4–6, *pa.s.*). A view of the basis cranii after these two parastoses have been removed (Plate VIII. fig. 2) is instructive as to their architectural value.

The lateral-line series does not give us any conspicuous "supratemporals;" but there is one attached to the "pterotic" which is worth description; it is shown in Plate VI. fig. 1, *s.t.* This curved, rod-shaped mucous bone is articulated below to a large falcate bone full of gland-burrows, but this is formed in the proximal part of the opercular fold; it is the "præopercular:" hence it is evident that the slime-canals do not confine themselves to the two forks of the lateral-line series.

Over the eye there is one "superorbital," and under the eye two thirds of a ring of "suborbitals" (Plate VI. fig. 1, *s.o.b.*, *su.o.*); these are thick and strong-rimmed where they contain the glands, thin and splintery at the outer edge. The suborbitals are developed in the superior edge of the subocular bar, external to the cartilage.

The bones of the upper jaw show the aberrant or subtypical character of the Salmon, the maxillary being dentigerous as well as the intermaxillary. The latter (Plate VI.

fig. 1, *p.mx.*) is much the most massive and broad bone of the two; it has a nasal and a dentary region, and its structure is peculiarly sponge-like and tubuliferous.

The maxillary (*mx.*) is scooped where it is overlapped by the intermaxillary; it sends inwards a scooped facet for articulation with the palatine (*pa.*), is rod-like in its dentigerous portion, and flattens out below, especially on the upper edge, which is overlapped by the malar or jugal. This third bone (Plate VI. fig. 1, *j.*) is lanceolate, scale-like, and fimbriated above, like the down-turned end of the maxillary; it is only loosely connected with the hinge-work of the mandible.

A very large splint covers the anterior two thirds of the cartilaginous mandible, largely on the outer, and less on its inner side: this is the dentary (*d.*). The fore end of its tooth-bearing part is strongly hooked; and this hooking of the mandible, so as to fit into the fore end of the beak, gives a peculiar character to the Salmon's face, especially in old males. On the angle of the mandible another splint is found, the angulare (*ag.*); it is small and rough. But the most characteristic bones investing the skull and face are those which form the gill-cover; these attain their highest development in the Teleostei. There are two sets, the "opercular" and the "branchiostegal;" for the second postoral arch, from which the primary opercular fold is developed, splits into a twin-series of pieces at an early stage of growth. In the Ganoids, even in the Sturgeon, three of the four very constant opercular pieces are found on each side; in these the "præopercular" or proximal bone is not differentiated, and in the *Polypterus* (see Traquair, *op. cit.* plate vi. fig. 7, *y.*) the præopercular is one with a large "temporal," as in the Frog and Ostrich. This single representative of the "squamosal" and the "præopercular" is, in the *Polypterus*, burrowed by mucous glands"*.

The "præopercular" of the Salmon is quite subcutaneous; it has the usual falcate form, is burrowed in a radiating manner by mucous glands; its attachment is by its fore edge, above to the hinder edge of the hyomandibular, and below to that of the quadrate (Plate VI. fig. 1, *p.op.*, *h.m*, *q.*).

Another piece developed in the proximal edge of the opercular fold is the interopercular (Plate VI. fig. 1, *i.op.*); it is ear-shaped, its narrow end passing within the præopercular is very thin, and it is marked concentrically and radially by *growth-lines*.

The most constant of these bones in the "Ganoids" is the "principal opercular;" it is the cephalic counterpart of those scutes which lie directly below the mucous bones (see 'Shoulder-girdle and Sternum,' plate i. fig. 9, *op.*), and the next plate behind it belongs to the trunk and is related to the shoulder-girdle as the "supraclavicle." The "opercular" is a large subquadrate bone in the Salmon (Plate VI. fig. 1, *op.*); it is elegantly marked with both kinds of growth-lines, and it articulates by its own cup with a ball on the hyomandibular,—that process which is the morphological counterpart of the

---

* I purposely mention the condition of the opercular bones in *Polypterus*, and that for two reasons—namely, to trace the Teleostean bones in each case to their simpler Ganoid representatives, and to incite Professor Huxley to reexamine his lettering in the woodcut in his Geological Survey Memoir (p. 22, figs. 16 & 17, H.M., S.T.).

"extrastapedial" in the Anurous Amphibia and in the Sauropsida. The bone lying below and somewhat within the opercular is the "subopercular" (Plate VI. fig. 1, *s.op.*); it is subfalcate, broad in front, very thin, and is elegantly marked by growth-lines. Together these four bones form the framework to the great outer and upper gill-valve in the osseous fishes; they are there subcutaneous bones, although they are represented by true cartilages in the "Plagiostomes;" and the principal opercular piece is also represented by a cartilaginous sickle in the young Frog; it becomes, as I have already shown, the Batrachian "annulus tympanicus" ("Skull of Frog," Plate VIII. fig. 7, *a.t.*).

Along the infero-posterior division of the second postoral arch there are twelve rays on each side (Plate VI. fig. 1, *br.s.*); these are flat, thin, and shaped like a knife-blade; their attachment is to the lower margin of the "epiceratohyal" bar on its outer side. These rays decrease in size from above downwards; they form one continuous series: in Teleostei generally, especially the Acanthopteri and Anacanthini, there are seven on each side; these are terete rods, arranged in two groups—the upper four attached to the outside; and the three lower end to the inside of the hyoid cornu. Here, again, the Salmon is seen to be only subtypical. There is an azygous bone at the base of this series (Plate VI. figs. 1 & 5, *b.br.s*); it is the ossification of intermuscular septa, and forms a sort of *isthmus*; it does not answer to the "uro-hyal" of the Bird, which corresponds to the "basibranchial" bar of the gill-bearing tribe, but should rank with the lateral rays and be called the "basibranchiostegal." Nearly twice as many rays proceed from the first branchial arch (Plate VI. fig. 3); these are pointed, flattened, arcuate ossicles, attached to the fore edge of the branchial bar; their direction is forwards and a little inwards. There is a single row of them on the first and fourth arches, but there are two rows on the second and third arches (fig. 4); these are so arranged as to form a *colander* through which the water is strained, as it is incessantly sent through the branchial clefts. In the Tadpole, as I have recently shown, similar structures commence on the branchial arches, which become conical elevations of cellular tissue, densely covered with tufted branchiæ, and they serve both for straining and for respiration. In the typical Teleostei they only partially grow into bony rays even on the first arch, but form little mounds covered with bristling teeth. The merely fibrous bones are thus easily classified by considering their relation to the parts beneath; they belong to the skin and its multifarious ingrowths; the osseous matter has ceased to be formed from their outer surface, leaving the skin thoroughly differentiated from the skeleton within. These parts have attained a higher morphological condition than in the "Ganoids;" but they cease at this, their culminating point, and do not reappear, many of them, at least, even in the metamorphic "Ichthyopsida." Those bones, however, which do reappear in the higher classes become very constant, and are never lost sight of again even in our upward march to Man.

The bony plates now to be considered (the *deep* laminæ) possess a peculiar metamorphic potency; for wherever they fasten themselves upon a cartilaginous rod or plate they, as it were, devour it, and convert it into their own substance; they have to be considered in connexion with the tracts of hyaline cartilage, which they are ever tending to obliterate.

The skull and face proper, deprived of the investing bones, is a very complex structure, a box above and a crate below; the two divisions will be best understood by considering them apart.

And first the box itself (see Plate VIII. figs. 1, 2, & 8), which is a compound structure, formed behind of axial parts, and before of facial. But, besides the axial and facial elements, there is to be considered how much is due to what the great ear-sacs superadd, and also what is superadded by the facial elements to the nose-sacs, which help to build their crypts; the eye-sacs are free, but are attached by a short cartilaginous pedicle (Plate VII. fig 3, *o.pd.*). There is one part of the skeleton which is truly azygous; and this is a primary, fundamental part, a part to which all the axial structures apply themselves; this is the "notochord." In the adult skull there is only one bone formed upon this fundamental part, the basioccipital; but the bony sheath of this axis acts upon symmetrical cartilages that appear very early, one on each side of the notochord; these are called, together, the "investing mass." This "investing mass". is the direct continuation of that part of the embryo which is so early segmented into the vertebral rudiments, yet itself, still closely embracing the azygous axis, is under the controlling influence of some force which prevents further segmentation. A quasi-vertebral ring or arch is, however, formed, the "occipital arch" (Plate VIII. figs. 1, 2, 7, 8); and this ring, seen from behind (fig. 8), has all the appearance and many of the characters of a vertebra. Only four of the bones seen from behind belong to this segment, the basioccipital (*b.o.*), the "exoccipitals" (*e.o.*), and the "superoccipital" (*s.o*): the three outermost pairs belong to the auditory capsule; they are "otic elements." But the "basioccipital" bone does not utilize all the "investing mass;" the notochord retires during growth, and the rest of the investing mass is ossified (not thoroughly) by the foremost of the otic bones, the "prootics." One remarkable change in the investing mass, as a whole, is the growth downwards of a lamella on each side, thus forming a covered archway; for in front of the retiring notochord the moieties of cartilage meet, and this viaduct is floored by the submucous bone which has been removed (Plate VIII. fig. 2), the "parasphenoid." All the true axial parts of the skull cease at the fore edge of the investing mass behind the pituitary space (*py.*); all the rest has a facial foundation, is built on the "trabeculæ," or has a secondary character as a development in the cranial wall. The compound eighth nerve (Plate VII. figs. 2, 3, 4, $_8$, and Plate VIII. figs. 2 & 3, $_8$) passes out of the skull between the postero-internal face of the ear-sac and the investing mass; it pierces the exoccipital in the adult. These latter bones present flat zygapophyses for the "atlas," which is also joined to the basioccipital, a notochordal 'buffer" remaining between the two. The "superoccipital" (Plates VII. & VIII., *s.o.*) is a massive bone; it does not, as in the "Sauropsida," receive any of the "anterior auditory canal;" and it extends halfway along the roof of the square postpituitary part of the skull, its bony matter ending abruptly in front. So much cartilage as is here ossified belongs, indeed, to the occipital ring; but whilst ossifying the cartilage had grown forwards to join a retral growth of a similar character which had crept along the cranial ridge all the way from the ethmoid (Plate VII. figs. 3, 4, 9, 10, 11, and Plate VIII. figs. 1, 4, 5, 6). This solid, subcarinate roof to the "great fontanelle" makes the endoskeletal skull of the adult Salmon very different to that of the adult Frog ("Frog's Skull," Plate IX. fig. 6), which is barge-shaped, and has a very imperfect "deck." These two types of skull do, however, conform to each other more than would seem at a hasty glance; even in the Frog the annular ethmoid roofs in the great opening to some extent, and the superoccipital cartilage has grown to the anterior sphenoidal region. We have, moreover, in the Salmon the lateral fontanelles (*p.fo.*), as in the Frog (Plate VIII. figs. 1 & 4). The rest of the square hinder part of the cranial box is almost entirely due to the impaction into the sides of the primordial cranium of a pair of very large ear-sacs, which coalesce very early with the investing mass, and send forwards from their anterior margin a lamina of cartilage which becomes the alisphenoid, and which is separately ossified. Anticipating the account of the earlier stages, I may say that the auditory sac is enshielded by cartilage from the outside, and is never totally encased as in the Frog. Also the huge size, in the young, of the semicircular canals causes upgrowths and swellings, according to their form, in the cartilaginous shield; and more than this, for the skull of the Fish, especially behind, is related to muscular masses, hence apophyses have to grow out for their attachment and leverage.

The eye reads all this in merely looking at the end view of the skull (Plate VIII. fig. 8), which shows a curious piece of architecture, the keystone of which and the *lesser* and *greater* wings thereof are produced and snagged. Five bony buds were during the first season grafted upon each swelling ear-sac, and they have transformed those simple encasements into the angular, ridgy, and winged mass which I have portrayed in figs. 1, 2, & 8 in Plate VIII. All these, save one, can be seen from the upper surface (fig. 1); they are the "sphenotic" (*sp.o.*), the "pterotic" (*pt.o.*), the "epiotic" (*ep.*), and the "opisthotic" (*op.*): the "prootic" (*pro.*) can be seen from beneath (fig. 2), partly sliced away from the outside (fig. 3), and in transverse section (figs. 4 & 5). The inner view (Plate VII. fig. 4) and the outer (Plate VII. fig. 3, *pro.*) are most instructive as to the most constant of the periotic centres. All the figures show how massive the periotic cartilage and bone becomes, and yet the labyrinth is only very partially imbedded in the mass. I borrow from the study of a prior stage the fact that the prootic commences in the thin anterior edge of the shield behind the exit of the first division of the fifth nerve, but enclosing the second; also that the "sphenotic" begins over the ampulla of the anterior canal, the "pterotic" over the ampulla and arch of the horizontal canal, the "epiotic" over the arch of the posterior canal, and the "opisthotic" over its ampulla.

The prootics nowhere display such curious and unlooked-for characters as in the

Osseous Fish; they beguiled both CUVIER and OWEN into the supposition that they were the great wings of the sphenoid. They surround part of the fifth nerve, send their osseous matter trespassing across the "investing-mass bridge," and also down into its deep descending keels—those most ichthyic protectors of the orbital muscles (Plate VII. figs. 3 & 4, and Plate VIII. figs. 2, 4, & 5, *pro.*). A broad synchondrosis exists between the prootics and the upper bones; and below this, on the inner side (Plate VII. fig. 4), the prootic is trilobate as it embraces the hinder division of the fifth nerve (5^b) and the "portio dura" (7^a). When the outer face of the skull has been sawn away (Plate VIII. fig. 3, *a.s.c.*, *pro.*), it can be seen that the ampulla of the anterior canal is partly imbedded in cartilage, and that the tubular communication of the ampulla with the rest of the labyrinth really burrows its substance and reenters the skull by the recess which opens outwards for the second division of the fifth nerve (5^b).

The bony bridge made by the prootics from the fore part of the investing mass articulates in front with the "basisphenoid" (Plate VII. fig. 4, *pro.*, *b.s.*), and behind with the basioccipital (*b.o.*). The two supero-external pieces carry the long concave facet for the wide head of the hyomandibular (Plate VII. fig. 3, and Plate VIII. fig. 2, *sp.o.*, *pt.o.*), and together form the "tegmen tympani," or rather its ichthyic counterpart, for here is no tympanum. The "sphenotic" is only half the size of the "pterotic," but it is a solid bone (see sections, Plate VII. fig. 11, and Plate VIII. figs. 4 & 5, *sp.o.*); it forms a strong forthstanding spur protecting the orbit, whilst the pterotic sends a similar spur backward for muscular attachment. Neither of these bones can be seen from the inner face of the skull (Plate VII. fig. 4) in a direct lateral view, nor can the "epiotic" or "opisthotic." The Bird differs from the Osseous Fish, whilst agreeing much with it, for it has all the five periotic centres; but the cartilage is not so thick as in the Fish, and it is entirely ossified; the "sphenotic" and pterotic are both small, but the former ("postfrontal") has the same shape as in the Fish and the same relation to the "alisphenoid" (see "Fowl's Skull," Plate LXXXIV. figs. 6, 8, 13, 14, *p.f.*, *a.s.*; compare especially fig. 14 with the section, fig. 4, in Plate VIII. of this paper).

In the Fish the huge sweep and vertical position of the semicircular canals makes the membranous labyrinth bear a much larger proportion to the cranial walls than in the Bird, in which the fore part of the periotic cartilage rapidly modifies itself in relation to the membranous cranium, and the anterior canal leans backwards; thus the "sphenotic" region grows out free from the labyrinth, and its ossicle looks like a mere epiphysis on the "alisphenoid." In the Bird the cerebellum excavates the cranial wall by its projecting lobe, and thus brings the little pterotic into view within; whilst the opisthotic wedges itself in between the prootic and exoccipital, and is greatly modified to encircle the mouth ("fenestra rotunda") of the small cochlea (see "Fowl's Skull," Plate LXXXV. fig. 3, *op.*, *f.r.*). The epiotic and opisthotic of the Salmon are both very backwardly placed in relation to the posterior canal (Plate VIII. figs. 1, 2, & 8, *ep.*, *op.*); they correspond in the adult Fish with their condition in the newly hatched Fowl or Chelonian*, the epiotic being the larger and more conspicuous bone. Here, in the Salmon, the opisthotic has an average development for a Teleostean; but in the Cod-tribe ("Gadidæ") it is very large, and reaching down to articulate with the basioccipital, ossifies the thin protuberant cartilage that encloses the sacculus; yet in them it is quite simple and ichthyic.

Getting in front of the borrowed part of the encasements of the brain, we come in front and at the sides of the pituitary body upon parts that, without a doubt, answer to the posterior sphenoid of Man. But in the Teleostean, at best, the basal part, the "Turkish saddle," is very unfinished and the "greater wing" is very small in proportion to the "petrosal" mass; yet the "alisphenoids" are unusually large in the Salmon for a Teleostean, and it has, what many others do not possess, namely a basal bone. The extent of the posterior sphenoid is best seen when part of the skull has been sawn off (Plate VIII. fig. 3), and its general form and relation in a transverse section (Plate VIII. fig. 4); from beneath (Plate VIII. fig. 2) and within (Plate VII. fig. 4, *b.s.*, *al.s.*) it can be studied instructively. Thus it will be seen that the basal bone is Y-shaped, that it leans backwards, that it sets its foot against the end of the orbito-nasal septum, and with its arms it props up the alisphenoids. At its bifurcation it leans against the prootic floor (Plate VII. fig. 4, *b.s.*, *pro.*) behind, whilst in front of it the optic nerves (2) escape. Between the arms of this bone the pituitary body is let down behind its single leg to find no "seat" to the "saddle," save what is formed beneath by the parasphenoid (*pa.s.*): the "sella" of the Bird is very similar to this (see "Fowl's Skull," Plate LXXXII.). The "alisphenoids," although in reality forming only the second cranial sclerotome, seem as if they would close-in the skull both in the Salmon and the Bird (compare the sections, Plate VII. fig. 11, and Plate VIII. fig. 4, with "Fowl's Skull," Plate LXXXV. fig. 11). Their relations are complex, and their formation will be better understood when we come to their development; the various figures, however (Plate VII. figs. 2, 3, 4, 11, and Plate VIII. figs. 1–4), will give a tolerably good idea of their architectural relationships. These bones are not brought into relation with the "investing mass" as in warm-blooded Vertebrata, but are separated from it by the great anterior passage for the "trigeminus" (see, from within, Plate VII. fig. 4, *al.s.*, *pro.*). Looking at the inner view, we see the alisphenoid propping up the thick supracranial ridge of cartilage, articulating behind with the prootic, and in front with the orbito-sphenoid (*o.s.*), whilst it rests upon the corresponding arm of the basisphenoid. The alisphenoids bound the lateral fontanelles in front (Plate VIII. fig. 1, and Plate VII. fig. 3, *al.s.*, *p.fo.*); they are separated externally by a thick synchondrosis from the sphenotic (Plate VII. fig. 11, and Plate VIII. fig. 4), and externally (Plate VII. fig. 3, and Plate VIII. fig. 1) they clamp, as well as underprop, the great cartilaginous "culmen cranii." The alisphenoids are much more distinct from the beginning from the trabeculæ than the same regions in the Bird; this distinction is shown in Plate VII. fig. 4, where in front of the orbito-sphenoid bone (*o.s.*) there is seen a sinuous fissure (*e.t.f.*). This fissure had been seen and drawn by me nearly three years before its development was made out. We should soon understand all things that belong to the skull if the sphenoidal regions were intelligible; they are not, however, as yet; for have we not just seen that even the posterior sphenoid is in front of the *axial* part of the skull, and that it grows out from the auditory capsule? Not altogether, however, for the alisphenoid is continuous above with cartilage which grows backwards from the "ethmoid," the ethmoid itself being built upon the foundation laid by the "trabeculæ"—a state of things enough to suggest to us the wearing away of morphological landmarks during the ages that are past. At present I have to describe the anterior sphenoid as it exists in the adult. Neither in the Bird nor in the Teleostean Fish can any part of the anterior sphenoid be seen either from above or from below (compare Plate VII. figs. 3, 4, & 10, and Plate VIII. figs. 1 & 2, with "Fowl's Skull," Plate LXXXVII. fig. 1, *os.* $_1$, *os.* $_2$, *ps.*); in the Bird the mesoethmoid meets the prepituitary part of the basisphenoid, and in the Salmon that prepituitary part is scarcely ossified at all by the Y-shaped bone, and the coalesced trabeculæ and the keel ascending therefrom are permanently unossified. Above also (Plate VII. figs. 1, 3, 10, *o.s.*), the cartilage of the great "culmen cranii" is not infected by the bony orbito-sphenoidal laminæ.

---

* They soon coalesce in the Turtle (*Chelone mydas*), and the compound bone, from its relations to the labyrinth, has been mistaken for merely an opisthotic (see HUXLEY, 'Anatomy of Vertebrated Animals,' 1871, p. 203).

A vertically transverse section of the coalesced orbito-sphenoids (there is no distinct presphenoid) shows well their structure, and how that they in this case, and not the ethmoid, close-in the cranial cavity. There is no "crista galli," and the perforation (Plate VII. figs. 3, 4, & 10, $_1$) for the "olfactory crus" is in the orbito-sphenoid. In the vertical section we see the twin bone grafted upon the "culmen cranii" above, and upon the thick swelling partition that grows upward from the shelving trabeculæ below. This double bone has metamorphosed some cartilage, but, like the Y-shaped basisphenoid, it is principally membranous; in the Sturgeon the orbito-sphenoids do not graft themselves upon the cartilage, and in the Fowl the two pairs of these bones have no orbito-sphenoidal cartilage to graft themselves upon (see "Fowl's Skull," Plate LXXXVI. fig. 11, *os.* $_1$, *os.* $_2$).

Foundation, side-walls, and roof,—all these are *facial* in the ethmoidal or nasal region: we are in front of the skull now, and the brain which did overtop and overhang every thing else in the head, and was, indeed, the largest thing there, is now relatively a retired series of small lobes and bands (compare Plate VII. fig. 4, showing the cranial cavity, with Plate I. fig. 8, showing a sectional view of the head in my earliest stage), so that the ethmoidal region can now be studied in an extracranial manner; we need not try to torture it into the vanguard of the vertebræ, or even into a "cranial sclerotome."

Save in expansion and size, the "trabeculæ" have undergone but little alteration in their under surface since the time of hatching, and even two or three days before; but above they have been subject to great change, by means of the various outgrowths that have sprung from them (Plate VIII. figs. 1 & 2, *tr.*). Looking at the bare skull from beneath, we see two symmetrical cartilaginous slabs, totally unossified, which together form a rough kind of cross deeply grooved along the mid line, for it has its equal moieties bevelled towards the middle. These moieties were formed of the flat tape-like trabeculæ, which met each other at an obtuse angle, so as to present a ridge towards the overlying membranous cranium. They were bowed out far beyond the boundary of the pituitary body, and by the end of each bowed part they coalesced with the corresponding moiety of the investing mass; now, however, there is no such connexion, the trabeculæ *are again free*, and they end by two small points with a rounded emargination between (Plate VIII. fig. 2, *tr.*). Each free point is the termination of a lanceolate convexity, and these convexities diverge in front, terminating on the outer edge of the trabeculæ. These facets have relation to the underlying "parasphenoid;" for here the flat part (Plate VII. fig. 2, *pa.s.*) becomes carinate above, and also gives off the "basitemporal alæ." But these facets have another meaning than their relation to the parasphenoid; for they are the first budding (arrested, indeed, and functionless) of the "anterior pterygoid processes" (see "Ostrich's Skull," Plate VII. fig. 4, *a.p.*, and "Fowl's Skull," Plate LXXXIV. fig. 11, *a.p.*). These processes are the "basipterygoids" of HUXLEY (see Proc. Zool. Soc. 1867, p. 418). Another pair of facets are formed beneath the arms of the *cross*; these are for junction with corresponding facets on the palatal bar; at these points the trabecular skull-base becomes greatly expanded. Corresponding with what I have said in my account of the development of the Frog's Skull, I call these outstanding parts, that tend to make the facial arches into a kind of basketwork, like the gill-crate of the Lamprey, the "facial connective growths." Those by which the palato-pterygoids join the trabecular bars appear during my rather long "first stage;" but those which foreshadow the second pair of connectives in the "Sauropsida" cannot be seen until the metamorphic changes are well nigh over.

Having sent out the "palatal connectives" the trabeculæ gradually contract: the part in front of the palatal connectives may be called the "cornua trabeculæ;" between those projections we have the transverse partition formed between the eyes and nose-sacs, whilst the further continuation of the trabeculæ is modified in relation to the nasal organs. The broad part immediately in front of the facets is the floor of the nasal sacs, and corresponds to the "subnasal lamina" of the Frog ("Frog's Skull," Plate VII. fig. 6, *s.n.l.*). Below, this is traversed by a curved ridge, which grows towards its fellow, anteriorly, in an elegant lyriform manner; the two do not meet at the mid line, but in front of them the thick short trabecular horns unite their substance, have a groove between them, and end in a bevelled facet; each "horn" is separated from its fellow at the end by a rounded emargination. Moreover, each horn has at its tip a pair of short, thick upper labial cartilages ($u.l.^a$, $u.l.^b$), the inner of which is the largest; they are joined by fibrous tissue, but they have a joint cavity between themselves and the "horns." Between the nasal sacs the trabeculæ are badly soldered together; in front the cartilage loses its substance in places, which becomes replaced by fat; further back, however, there is a large, apparently meaningless, cavity, filled also with fat. Below, between the converging arcuate ridges, a large canal is seen, occluded in its middle by the largest of four or five swellings of cartilage, that thus clumsily, as it were, have resoldered the trabeculæ together. Looking at the upper view (Plate VIII. fig. 1, *al.s.*), we see feeble attempts at the formation of "aliethmoidal" and "aliseptal" laminæ; but the "septum nasi" only exists as the clubby coalesced "trabecular horns." Above, the cartilage near the mid line is imperfect; then, behind that, we see a piece of the "lamina perpendicularis" (*p.e.*) crop up to the surface, and behind this the opening which is the anterior remainder of the "great fontanelle," overhung by the free fore end of the "culmen cranii." This remnant of the "fontanelle," and the vacuity a little in front of it, both open into the great mesoethmoidal fat-cavity (Plate VII. fig. 4, *m.n.c.*). Is there any morphological meaning in this fat-cavity, and in these deficient solderings of the "trabeculæ cranii" in front of the cranial cavity?

If the reader will refer to the fourth Plate in JOH. MÜLLER'S magnificent work on the Myxinoids ('Vergleichende Anatomie der Myxinoiden'), he will be able to answer this question for himself; meantime I will refer him to the sectional views of this Salmonine remnant of the azygous nasal sac of the Myxinoid with its "Nasenöffnung" above and its "Nasengaumenöffnung" below (see Plate VII. figs. 4, 7, & 8, *m.n.c.*).

The facets for the palatines are not on the widest part of the ethmoidal region; for, above, the huge "ectoethmoidal" wings form both wall and roof to the orbit in front, and, largely ossified, they form the so-called "prefrontals" (Plate VIII. figs. 1 & 2, and Plate VII. figs. 1, 2, 3, & 9, *l.e.*). These elegant shelving ethmoidal wings are separated above by a notch from the "mesoethmoidal" region, which has at that part become the "culmen cranii." Exactly between these antorbital expansions the "mesoethmoid" is, as has just been stated, occupied by fat, but further backwards it reappears a veritable "lamina perpendicularis" (Plate VII. figs. 4 & 9, *p.e.*). Outside the fat-cavity the antorbital wall is pierced by the "olfactory crus" (I); in the lateral view (Plate VII. fig. 3, I) this can be seen emerging from the orbito-sphenoid behind, and reappearing in front of the "ectoethmoid" in the recess for the "nose-capsule." The ridge above this recess is the rudiment of the "aliethmoid" of the Bird and other high types, and the ridge below is the edge of the "subnasal lamina" of the Frog.

If the reader will refer to my paper "On the Fowl's Skull" (Plate LXXXVI. figs. 8 & 9), he will see that the "prefrontal" bone answers to the region called "pars plana," the seat of the "middle turbinal," whilst the upper unossified part of the lamina is the counterpart of the foundation for the "upper turbinals." Of course there can be no "inferior turbinal," as there is no specialized "septum nasi" from which it could grow as an outgrowth from an "aliseptal lamina."

The Fowl gives voice as to the meaning of the "culmen cranii;" I had described the retral continuation of the ethmoid along the mid line, above the olfactory groove, as the "crista galli," but corrected this error (see "Fowl's Skull," note to p. 762, and Plate LXXXI. figs. 3, 4, & 5, *eth.*). If this elegant roof had continued its growth backwards in the Fowl instead of degenerating into a spike, we should have had what does appear in the

Salmon's skull; I am, of course, supposing an equivalent growth from the "superoccipital." When we come to the earlier stages of these parts the meaning of what is here written will become much plainer, and the reader will do well to keep the adult condition of the various parts always before him whilst studying their incipient stages.

With regard to the next arch, the "pterygo-palatine," I must confess that the state of things in the Frog made me hesitate in classing this arch with the rest as a morphological equal. It certainly has a sluggish development even in the Osseous Fish, where it attains to its fullest growth and is for a time entirely distinct; moreover it only acquires the typical sigmoid form of the facial arches just as it is losing its distinctness from the first postoral bar. This arch is but little developed in the Urodeles, and scarcely chondrifies at all in the Sauropsida and Mammalia. Yet my figure of it in the Chick ("Fowl's Skull," Plate LXXXI. *pa.*, *pg.*) is perfectly correct, and my early stages of the Salmon will show a marvellous amount of harmony between the "Teleostean" Fish and the "Carinate" Bird in this and in many other parts.

To put the matter clear at once with regard to the Frog, let me repeat what I have described in that creature—namely, that at first there is no pterygo-palatine arch whatever; that it is fairly suppressed during the whole of the proper ichthyic or larval period, only existing as a feeble "secondary connective;" that when the tail is disappearing and the lungs developing it only has reached to the condition of the Lamprey; and, finally, that it never becomes distinct, either from the trabecula in front or from the mandibular pier behind. I am somewhat inclined to attribute the feeble and slow development of the second preoral arch in the Salmon to the prepotent growth of the eyeball; yet that will not account for its suppression in the Frog, where the eyeball is relatively much smaller (see "Frog's Skull," Plate IV. fig. 1, and Plate V. fig. 1).

When the investing parosteal bones are removed from the facial arches of the Salmon we have what is displayed in Plate VI. fig. 2, and Plate VIII. fig. 9. Let an imaginary line be drawn through the substance of the cartilage that separates the "mesopterygoid" and pterygoid (*m.pg.*, *pg.*) in front from the metapterygoid and quadrate (*mt.pg.*, *q.*) behind: such a line will pass through a knob of cartilage above; this is where the "orbitar" process of the mandibular arch has coalesced with the inturned or hooked upper (=posterior) end of the pterygo-palatine rod, and the line drawn will show the whole extent of the coalescence. These parts do not coalesce in the "Abranchiate Vertebrata." The dentigerous bony palatine does not wholly ossify the palatal region of the bar, a large knob articulates with the maxillary near the end of the prepalatal spur; the "ethmo-palatal," an earlier process, tied to the trabecular facet by strong fibres, does not ossify, and the postpalatal portion has a soft core. The "mesopterygoid" (*m.pg.*) overhangs the outer side (Plate VI. fig. 2), but is large, convex below, inturned, then concave, and then flat behind, on the inner side (Plate VIII. fig. 9). This flat posterior portion overlaps the pterygoid (*pg.*), which clamps the lower edge of the bar behind, is most developed on the inner side, and, like the "mesopterygoid," overlaps the inner face of the quadrate bone. Here there is no "os transversum" or "ectopterygoid," and the *innermost*, or submesial pterygoid, is much larger than the pterygoid, the counterpart of the "internal pterygoid plate" of Anthropotomy. In Fishes this bone is very constant from the Ganoid Sturgeon to the Teleostean Perch; I have never seen it in the Amphibia, and as yet only in *Anguis fragilis* amongst the Reptilia; it has only failed my search in the Ostriches and Fowls amongst the Birds, and I am satisfied that it is not uncommon in the Mammalia.

In the ordinary language of embryologists the mandibular arch is called the first facial, for the palato-pterygoid is mostly reckoned as a rudiment growing out from the mandibular rod above, whilst the "trabeculæ" had all along, until Professor HUXLEY showed their true nature, been regarded as processes growing forwards from the "investing mass." In my description of the Frog's skull the mandibles are, on account of the suppressed and non-separate condition of the palatals, classified as the second facial arch; in this memoir the mandibles will be considered as the third arch, but the series must be divided into the "preorals" and "postorals." In all Teleosteans, and in some to a most extreme degree, the gape of the mouth is placed at a great distance from the head. In such Fishes as the Dory (*Zeus*), in *Epibulus*, in *Fistularia*, and in the "Hippocampoids," there is found the extreme of Teleostean modification of the mouth; but in the most moderate degree of specialization, as in the Salmon, the hinge of the jaw is carried away from the head, first, by a double condition of the quadrate, and, secondly, by the descent of the top of the pier away from the side of the head and its attachment some distance down to the overgrown pier of the next arch (Plate VI. fig. 2, Plate VIII. fig. 9). All this modification shows that the Teleosteans are Vertebrates specialized to the uttermost for their own kind of life, and that they are indeed one of the culminating branches of the vertebrate *Life-tree*; hence, I think, arises the wonderful harmony, in many respects, between their structure and that of the branches and twigs of another "leader" in this genealogical tree: I refer to the Bird.

The top of the mandibular pier, "metapterygoid" (*mt.pg.*), is not let down so far in the Salmon as in the more typical Teleosteans, where it is commonly on a level, at its top, with the attachment of the "stylo-hyal;" it passes halfway down, and both it and the succeeding pier being broad, it largely overlaps its successor. The whole pier is oblong, the upper bone, "metapterygoid," being squarish with produced angles, the lower, the "quadrate," triangular, with a free grooved posterior wing, and at its inverted apex a condyloid facet.

Observe that the synchondrosis between these bones rises in front of the upper piece into a boss, and swells out behind it into a knee; the boss is a primordial lobe; the "orbitar process" lies in front of the eye in the long horizontal mandibular pier of the Tadpole (see "Frog's Skull," Plate v. figs. 1 & 3, *or.p.*); the "*knee*" is the retention of the original curve of the facial arch, which I shall afterwards describe. All in a row are these *knees* or bends in the postoral arches; that on the trabeculæ has been lost, and the curved part of the pterygo-palatine arch has coalesced with the orbitar process of the mandibular pier. On the inner side (Plate VIII. fig. 9, *qu.*) the quadrate is grooved, between its broad part and the periosteal wing, to receive a peg from the next pier, and by this elegant carpentry the two piers are strongly coupled to each other.

The free part of the mandibular arch is one third longer than the pier; it is strongly clamped by a bone which is grafted upon it, most on the outer side; this is the articulare.

The "coronoid process" is part of this bone, and not due to the Meckelian rod; but the hooked process behind the angular process is due to the character of the original segmentation of the terminal piece. The "articulare" is snagged, ribbed, and splintered, and only ossifies the proximal part of the mandible, the rest being a strong, rounded, gradually tapering rod (Plate VIII. fig. 9, *ar.*, *mk.*).

As in the Bird there is no "mento-meckelian" bone, such as occurs in Frogs and Man. No morphologist has ever been more richly repaid for his labours than he who traced the metamorphosis of the second "postoral" in the Frog; equal pleasure and profit has attended the unveiling of the mystery of the Teleostean hyoid arch. This arch has its fullest development, if not its highest metamorphosis, in the Osseous Fish. On each side of this huge *swing* there are seven bones and four broken-up segments of cartilage, besides an azygous pier, which has its own bony plate, besides, in the Salmon, thirty-three parosteal bones. *How* all this has been made out of a single pair of facial rods let embryology declare. Not now, however; at present let it be assumed that the second "postoral" does cleave a long cleft down its substance, that the foremost larger part stays atop, and that the narrower part slides slowly but surely down to the *knee* on the synchondrosis of the foremost piece. The great factor in the swinging-power of the Fish's mouth is the uppermost part of the larger anterior division of the arch. At first hooked beneath the fore part of the auditory capsule, it keeps under a ledge formed by the bulging of the horizontal canal, and then the hinder piece having escaped downwards out of its way, it grows along nearly to the extreme end of the sac.

The long scooped facet for this element, the "hyo-mandibular," is shown in lower and side views of the skull (Plate VII. figs. 2 & 3, and Plate VIII. fig. 2). Below the unossified, long, convex condyle of the hyo-mandibular there is a knob for the cup on the opercular (*op.c.*); below this the bone gradually narrows and stops short above the knee like bend; then comes a broad cartilaginous tract, and below that the ossified "symplectic" peg (*sy.*), which turns forwards to fit into the groove of the quadrate. On the inner and posterior face of the out-bowed synchondrosis there is a small rod of largely ossified cartilage, this is the "stylo-hyal;" it is the *secondary* suspensorium of the second narrower division of the second "postoral," and is attached by ligament to a cup above and to a cup below; there is evidently a small joint-cavity above within the ligament, but not below (Plate VIII. fig. 9, *st.h.*). I do not find this "stylo-hyal" (Cuv.) until I come to the fourth stage, and it has no separate representative in the Frog; yet in Fishes it is found from the lower "Ganoids" (the Sturgeons for instance) up through all the higher osseous kinds; not, however, in "Myxinoids," nor "Plagiostomes," which are represented by very early conditions of the Teleosteans.

This dropped semi-arch, thus suspended, is very large, and carries the infero-internal gill-cover fold, the branchiostegal membrane with its many parosteal rays. The main arch has an arcuate outline within, is flat above and knobbed below; but this knobbed part, from the Sturgeon upwards, is segmented off, is cupped to fit to the convex end from which it has been taken, but there is no joint-cavity; this distal part has two bony centres, and the upper third of the main arch has a centre distant from the rest of the bar. From above downwards "epihyal," "ceratohyal," and hypohyal; these may be the names, for the distal piece answers to the "hypobranchials," and not to their azygous keystone; it has its own keystone, the "glossal," or rather "basihyal," a thick flattened bar, covered at top, sides, and end with a dentigerous ectosteal plate (Plate VI. fig. 1, and Plate VIII. fig. 9, *ep.h.*, *c.hy.*, *h.hy.*, *g.h.*). These huge "cornua" are strongly tied to the sides of the basal piece, near its end, and the first "basibranchial" runs up to the converging bars (Plate VIII. fig. 9, *b.br.*).

The smaller arches, much smaller *from the first* in this high type, are devoted to respiration, all save the last, and are seen from their inner side (Plate VIII. fig. 9, *br.*); they are a regular series, decreasing, however, in size and specialization from before backwards; they pass below within the hyoid arch, as it passes within the mandibular, telescopically. Each bar is normally segmented transversely into four cartilages, conjoined by a strong, short, fibrous ligament, and each of these has its own ectosteal sheath. The fourth arch has its upper piece unossified, and wants the distal segment; the fifth is still more aborted, having a small separate upper cartilage and a larger lower piece which is ossified; this arch is dentigerous and abranchiate, and is called the "inferior pharyngeal." The normal arches have their segments called "pharyngo-," "epi-," "cerato-," and "hypobranchial," and the keystone pieces are the basibranchials; there is only one for the fourth and fifth arches, and it is unossified and segmented from the bar in front; the three foremost have coalesced. These arches tend to fork above; the first segment sends off a sort of pedate process (Plate VIII. fig. 9, *p.br.*), the next has its upper segment bifurcate, and also the next, the third articulates with the fourth and sends a fork from its "epibranchial" segment, the fourth sends out an epibranchial lobe, somewhat 3-lobed itself, and the fifth is simple. The third basibranchial (Plate VIII. fig. 9, $b.br._3$) is clamped on each side by a descending process of the corresponding "hypobranchial," and it sends downwards a cartilaginous hook from its lower end; these are for muscular attachment.

First Stage.—Salmon-embryos, before hatching, with the facial arches simple.

With such specimens before him as those from which the following descriptions have been taken, it is not a little difficult for the worker to keep himself from wandering into general Embryology.

This snare will, however, be avoided as much as possible, reference to the general bearing and relation of parts being made just enough to make the matter clear to the reader. As an introduction to this starting-ground, the inquirer will do well to read the latest and best abstract of what is known as yet of the development of the Vertebrata; this is given in Professor Huxley's new work entitled "A Manual of the Anatomy of the Vertebrated Animals" (see pp. 3–13).

In the younger embryos which formed the subjects for my *first stage*, the "primitive groove" had not closed over the cephalic (Plate I. figs. 2, 4, 5) nor over the caudal extremity of the long tape-like germ.

At present the rudiments of the nose, eyes, and ears are very imperfect, the olfactory sacs are merely (Plate I. fig. 1, *ol.*) pits surrounded by a circular ridge of the "epiblast," the folds of the eyeball (*e.*) are not coalesced, and the auditory involutions (figs. 1, 3, 6, 9, *au.*) are still widely open.

The peripheral portions of the "blastoderm" extending over the yelk form a bag so wide open above that its rim reaches to within a short distance of the posterior margin of the mouth, close behind the converging Meckel's cartilages (Plate I. fig. 1, *u.v.*, *mn.*). In this early stage all the principal parts of the head have their rudiments differentiated; but these rudiments lie in the midst of a very soft stroma, and much care has to be taken in hardening and even colouring the specimens before the various organs can be made out. The most immature embryos worked out by me are illustrated by figs. 1 & 2, Plate I.; and although the parts which have begun to form the skull and face are *coloured* as though they were cartilaginous, yet their actual condition was merely that of more consistent tissue than that in which they were imbedded. This tissue was indeed composed of the "mother-cells," very small, of hyaline cartilage; and it could easily be seen, in the case of the facial arches, that the apparent *rods* were merely *tubes* composed of finely granular matter, lying in and also enclosing a thoroughly diffluent tissue. As to *degree* of development, the first two pairs behind the mouth were the rods most distinct, next to them the branchial-arch rudiments, then the trabeculæ, and lastly the "subocular" bands, the rudiments of the pterygo-palatine arch.

My illustrations will appear to the reader as representing strangely twisted, *oblique* objects; they are true to Nature, however, in that the upper and lower planes of the head, in the unhatched Salmon, are placed in such an oblique manner that only one *eye-dot* appears when the eggs are examined with a pocket lens (see Plate I. fig. 4, the head seen from above). Hence all bird's-eye views of the head, whether upper (fig. 2) or lower (fig. 1), are strangely unsymmetrical; and it is useless at present to seek in these imprisoned young for either the swelling cerebral vesicles, with which the embryologist is so familiar, or for that very important tilting-over of the fore part of the brain, causing the "mesocephalic flexure."

The flat edge of the down-kept membranous cranium is seen from below like a second superciliary ridge (Plate I. fig. 1). One eyeball, it may be indifferently either *right* or *left*, is fully seen below, whilst the other is mainly seen above, and only peeps down to the lower plane. So large are the ear- and eye-sacs that they overlap each other; this is seen in specimens that have suffered no compression. Most of the structures with which I have to deal are formed in what I would call *secondary strata* of the "mesoblast," enfolded very largely in their differentiation by involutions, *tuckings-in*, of the "epiblast;" these are mainly on the under surface of the head, which now just projects free of the yelk mass. This *subcranial* mass of tissue becomes *thickened* in certain directions, *puckered* into more distinct ridges and furrows, and *cloven* into bands or rods, the epiblast freely growing into every available cleft, and giving additional separateness to the mesoblastic structures. Hence, in the cephalic part of the embryo, the so-called mucous membrane, that of the mouth and fauces, is not a hypoblastic production, but is formed by ingrowths of the "epiblast" down to the point where the true mucous membrane begins; the lining of the mouth and fauces should be rather called "inner skin" than "mucous membrane." By means of the peculiar thickenings and puckerings of that part of the blastoderm which underlies the projecting head, we get an *upper* and a *lower* palatal region; in the higher Vertebrata, the Crocodilia and the Mammals generally, a third and lowest palatal floor is formed by a peculiar infolding of the *supraoral* strata.

The uppermost and also *innermost* "palatal bands" ('Gaumenleisten,' MÜLLER, see his 'Myxinoids,' pl. 4) are formed out of a delicate tract of "mesoblast" immediately underlying the membranous cranium, under the rudiment of the first vesicle (Plate I. figs. 1 & 8, *v.* 1, *tr.*); they are invested below by a tract of "epiblast," the primordial mouth-roof, which is made and *exposed* by the puckerings of the "blastoderm." These are in reality the first facial arch; their relation to the rest of the series is seen in a sectional view (Plate I. fig. 8, *v.* 1, *tr.*); the huge eyeball and the dipping-in of the tissues to form the mouth-cavity makes their relation to the rest of the series difficult to understand. RATHKE, who regarded these bands as continuations of the "basilar plate" or "investing mass of the notochord," called them the "rafters of the cranium," *trabeculæ cranii*. Their morphology is much more easy to be understood in the embryo of the Frog; whilst the mouth is hard to interpret in that type, and comparatively easy, as it appears to me, in the Salmon. A much smaller object than a rafter would have served better as a comparison for those rods which stand in the van of the facial phalanx, namely a pair of *curved forceps* (see Plate I. figs. 1 & 2, *tr.*). That these bands belong to the same series as the rest of the facial arches, and that they are formed out of the same structure of the "blastoderm," is evident if we examine them in the Frog (see "Frog's Skull," Plate III. fig. 3, 1, *tr.*, and Plate IV. fig. 1, 1, *tr.*), where they are the largest of a series gradually decreasing in size backwards. Moreover, in the second stage of the Frog's skull (Plate IV. fig. 1), when the trabecular rods have acquired the curve inwards above which is peculiar to the series, then they are really subocular rods, for they lie in the very substance of the outside of the cheek, and curve round under the eye, there being at that time no pterygo-palatine arch in their way. But the Salmon-embryo at its earliest differentiation of organs shows itself to belong to a new and higher dispensation; in its earliest infancy it bears the impress of a nobler type. The blades of these tiny forceps are perfectly simple in form, they are not riveted anteriorly (=below); this anterior part has neither the second lobe nor the outward turn, which makes them *lyriform* afterwards; the blades pass round the pituitary body, to which they are as nearly related at the beginning as they are in the Frog in my third stage (*op. cit.* Plate IV. fig. 9, *tr.*). There is no clear distinction at present between that layer of epiblast which forms the skin and that which invests the rudiments of the brain as the primordial or membranous cranium. Hence the position of the trabeculæ (see Plate I. fig. 8, *tr.*) is between the epiblastic cerebral tube (imperfectly closed) and the palatal skin (*enderon*), and they are formed out of and enclosed in that thin tract of "mesoblast" which becomes differentiated not only into these trabeculæ, but also into the membranous cranium*.

There is a great difference in the embryos at this early stage; for while some have their mouth gaping and the angle of the mandible drawn back, others (see fig. 3) have a peculiar likeness to their *sire*, the old male Salmon, the rudiments of the lower jaw being very long and strongly hooked upwards; these, however, are best for a contemplation of the morphological nature of the mouth. The mouth of the Frog-embryo caused me so much trouble that I almost despaired of classifying it (*op. cit.* p. 145, and note), but now I seem to "feel the light" from this translucent embryo. Looking at my third figure, and considering that the foremost arch is wrapped up in the succeeding folds of the face, then the *seriality* of the converging bars and intervening furrows will be understood.

The facial clefts formed by dehiscence of the thinned interspaces of the rib-like thickenings of the face are not formed at the same time; the first cleft, which I have discovered between the first and second *preorals*, does not become thoroughly distinct until after hatching. The first *post*oral cleft is now visible (fig. 3), but *it* has lagged behind the second, for the cleft *in front* of the mandibular bar was formed first.

That cleft is not one of a pair like the rest, but is double, and forms an azygous V-shaped opening, bounded in front by the second preoral, and behind by the first postoral bar; this is the mouth (*m*). The palatines are primordial structures as distinct, even now, as the eyeballs which rest upon them; they bound the opening gape above, and reach in front to the nasal sac, and behind to the auditory capsule, overlapping there the remarkable superorbital band (*s.ob.*). Now, in conformity with their long suppression and late appearance in the Frog, even here in the Salmon their differentiation into hyaline cartilage is very tardy; in my fourth stage the rod will be seen to enclose a protoplasmic pith, and in the fifth their apex will have melted into the fore edge of the next arch behind†.

The section (Plate I. fig. 8, *m*) will show what space is forming for the mouth and fauces between the infoldings and thickenings that have formed beneath the brain. The pituitary body (*py.*) lies between and almost *upon* the converging mandibular rod ($v._3$), and these terminate above in a transverse line a little behind the pointed end of the notochord (*nc.*). An equal space exists in front of the pituitary body, between it, behind, and in the membranous cranium and subocular bar in front: there is no space between the trabecula and the cranial sac; it cleaves fast to the skull from the first.

---

* In the longitudinal section (Plate I. fig. 8) the trabecula (*tr.*) is coloured, as though it were *showing through* the palatal skin, for it could not be shown in a section of the skin, being at a little distance from the exact mid line; the same is partly true of the next bar, pterygo-palatine, but the rest are made naked at their very ends.

† Here let me warn the reader against relying on terms of mere local relation, such as *pre*frontal, *post*frontal, and the like: the term *sub*ocular is good for immediate use in description; but at first the trabecula is the "subocular" in the Frog-embryo; then in the Tadpole (compare "Frog's Skull," Plate IV. fig. 1, *tr.*, with Plate V. fig. 1) it is the mandibular pier (1st *post*oral) which is the subocular bar; here, in the Salmon, the subocular bar is the rudiment of the "pterygo-palatine arcade." We must not rest until our knowledge is put upon a sound *morphological basis*.

Several minor stages and various conditions of the mandibular arch (third facial, first postoral) are given; perhaps the most important is my very earliest (Plate I. fig. 1, $v._3$). Here it is but a granular tube filled with and enclosing fluid stroma, and yet it has three most important regions marked out. The first of these is the slender "metapterygoid" band, running up and curving inwards as far as the next arch: this part has its normal position under the fore edge of the auditory capsule.

The next region is the middle, the swelling part, which shows the commencement of the "orbitar process," here, at the beginning, having a position which it only acquires in the fifth or metamorphic stage of the Frog (see "Frog's Skull," Plate v. fig. 1, and Plate VII. fig. 1, *or.p.*). The third region is the *Meckelian*; it becomes afterwards a free segment, the mandible; it is clubbed at its end as in the Tadpole, but it lies as yet some distance from its fellow. In more advanced embryos (Plate I. figs. 3, 7, 9, $v._3$) the first postoral has grown very much; it is very variable as to length, even at exactly corresponding stages, and the clubbed Meckelian end has spread into a flat spatulate expansion (Plate I. fig. 7, and Plate II. fig. 1, *mn.*). This bar is not dissected out in figs. 3, 6, & 9, but in fig. 7 we see its uttermost development as a simple tape-like band of cartilage, its flat apex and "orbitar process" turned inwards beneath the front of the auditory sac, and its Meckelian region converging to its fellow in front, and flattening out at the symphysis. The apex, with its "orbitar" expansion is well shown with its relation both to eye- and ear-ball in fig. 5 ($v._3$, *mn.*).

The first clear differencing and formation of the second postoral (hyoid) is shown in fig. 1 ($v._4$); it has an enlarged and incurved apex, and is thickened in the middle and below: the umbilical vesicle (*u.v.*) reaches the mid line between the two bars. This condition lasts but a short time; for in embryos but a little more advanced (figs. 3, 7, 8, 9) the part of the blastoderm enclosing the yelk has retired so as to expose the under surface of the lingual region, and even the opercular fold of the second postoral bar; moreover the ear-sac (*au.*) has still its great lipped opening. Now, but not before, the first postoral cleft (fig. 3, $cl._3$) is very distinct, and the top of the long hyoidean band of cartilage largely curls itself under the auditory sac (figs. 3, 5, 7, 10, $v._4$, *au*). Also we now find the first of a series of azygous cartilages, which are denied to the three front arches; this is the "glosso-hyal" or true "basihyal" piece (figs. 7, 8, *g.h.*). But, further, the first two postorals would be remarkably alike, save that the apex of the second is broader and more developed even now than that of the first, so early does each arch show the marks of its hereditary modification. As all the arches have a tendency to project forward, this keystone piece stands mostly in front of the lateral bars; it will be seen to be the same with those that succeed. These arches are formed in that part of the blastoderm which lies within the huge opening of the "umbilical vesicle;" that vesicle attaches the fore part of its neck, at present, to the under surface of the rudimentary tongue, with its enclosed "basihyal" cartilage (Plate I. figs. 3 & 8, *u.v.*, *g.h.*, *v.*$_4$), and because of the heart (*h.*), which is situate in the mid line, these bars are wide apart at present. There are five pairs of rods behind the hyoid arch; these become the branchial arches (*br.*), all save the last pair, which become dentigerous and are always feeble; they all suffer from the general non-symmetry of the head, are all smaller than those in front of them, but all except the last early acquire the elegant sigmoid in-hooked form. That these Salmon-embryos rapidly assume the more highly specialized characters of a noble "Teleostean" Fish, and are much further from the lower "Myxinoid" types than the Frog-embryo, is evident if we compare my very earliest condition (Plate I. figs. 1 & 2) with the counterpart stage in the Frog ("Frog's Skull," Plate III. fig. 3).

That part of the primordial skull of the Salmon which is *quasi-vertebral* (its "peri-notochordal" region) is very small, and forms the floor for the "medulla oblongata" (Plate I. figs. 2 & 8, and Plate II. fig. 2, *nc.*, *i.v.*). Of all the facial arches the trabeculæ come nearest to the investing mass in this type (Plate I. figs. 2 & 5); whilst in the Frog (*op. cit.* Plate III. figs. 4–6) they are the furthest from it. In a number of specimens I was able to make out, most clearly, the free truncated ends of the moieties of the "investing mass" or "basilar plate" (Plate I. figs. 2 & 3, and Plate II. figs. 4 & 5, *iv.*). The abrupt manner in which this "*præ*-protovertebral" tract ends in front is quite remarkable; it is as square as though it were really one of the proto-vertebræ, the foremost*.

In my most immature specimen (Plate I. figs. 1 & 2), studied as a transparency, but in the upper view (fig. 2), having the skull-floor partly laid bare from above, the twisted condition of the embryo gives the notochord and its investment a turn toward the left side; it is seen to reach the trabeculæ; but its investing moieties (*iv.*) quite run short, so that there is a peculiar and sudden abortion of the primordial vertebral structure. All that is built upon this foundation is the occipital arch and the "prootic bridge," and the mansion of the brain is built up from many a source foreign to these mere axial rudiments.

There is a skull-rudiment which develops in a manner unexpected by me; this is the primary "superorbital bar" (Plate I. figs. 1, 2, 3, 4, 6, 7, *s.ob.*); it is much more than the seat of that frequent additional bone which overshades the eye in Fishes; in the fifth stage I shall describe the cartilage which develops in it as a boundary to the "great fontanelle."

---

* I can now throw a little more light upon the Fowl's skull than when I wrote upon it. Professor HUXLEY gives a figure of the primordial skull of the Fowl in his 'Elements' (p. 138, fig. 57, F^1), and reproduces it in his 'Manual' (p. 18), which agrees very closely with my first stage (Plate LXXXI. fig. 2). In these figures the "trabeculæ" converge towards each other over the ends of the investing mass, and this mass terminates in a truncated manner on each side, the *squared end* looking *forwards* and outwards; the two structures are not seen, however, as distinct. In my next stage (Plate LXXXI. fig. 8) the blades of the trabecular *forceps* have opened out, and the investing mass is now mesiad of the apices of the trabeculæ, which are plainly seen. Not so plainly seen, however, as in the third stage (Plate LXXXII. figs. 1, 2, 3, *tg.*), where these apices have become long, free, rounded rods, with a cellular interior, such as I find in the trabeculæ of the embryo of the Boa, *Eunectes murinus*.

The auditory sac is only partially invested with cartilage, and at this stage it is an irregular and fenestrate shield (figs. 2 & 5, *au.*), imperfect within, above, and below (Plate I. figs. 2 & 5, and Plate II. figs. 2 & 4). As far as I can see from various views, the great blastodermic involution which forms the ear-sac shuts off the labyrinth before the outer opening begins to close, although this gaping space itself is very temporary. The sac itself seems to be formed from the epiblastic layer, which has developed a roof to the labyrinth over the rudiments of the three semicircular canals, thus shutting off the new sense-organ from the outer skin and its primordial opening. But the mesoblastic layer has developed immediately around the new *racemose labyrinth* (Plate I. figs. 2 & 5) a partial investment of young cartilage; this cartilage has not crossed over below the primary opening, nor has it finished the floor (see Second Stage, Plate II. fig. 4), a deficiency being left there for several months; nor does it ever in this Telostean wall-in the labyrinth, craniad. The finishing of the upper and lower faces of the periotic cartilage is remarkable and instructive; and whilst the primordial opening of the sac is closing-in the semicircular canals are getting more roof, which grows from before backwards, and which is not completed in newly hatched fry (see Fourth Stage, Plate III. fig. 6, *ep.*). No such gradual or even *partial* growth of cartilage is seen in the Frog; in that type the epiderm, *at least*, is closed over the sac before hatching, when the head and tail of the embryo *pitch* very little beyond the yelk-mass. Then, indeed, there is a primordial "fenestra ovalis" ("Frog's Skull," Plate III. fig. 3, and Plate IV. fig. 1), but otherwise the cartilaginous ball is complete, except where it allows the "portio mollis" to enter on the opposite side. Soon (that is in Tadpoles less than half an inch in length) this fenestra is filled in, again to reopen by the segmentation out of its own substance of a *stopper*, the "stapes" (*op. cit.* Plate IV. fig. 7, and Plate V. figs. 1, 2, & 4).

We shall see the last of the primordial fenestra ovalis of the Salmon in the seventh, or first summer stage, but I have already shown that there is no reopening.

The auditory cartilage is entirely free at first, but as my first stage is passing into the second it coalesces with the "investing mass" by two connective bands that enclose the primordial "fenestra ovalis" (Plate II. figs. 2 & 4); this takes place a little before the fusion of the trabeculæ with the same plates. The foregoing description will be now supplemented, and in some degree recapitulated, by a description of the transverse sections. Two of these sections (Plate I. fig. 10, and Plate II. fig. 1) are made through the eyeballs, and two through the ear-sacs (Plate I. fig. 11, and Plate II. fig. 2). The first of these sections (Plate I. fig. 10) is of a very immature but unusually symmetrical embryo, one answering to figs. 1, 2, & 8 as to development. At this part the "umbilical vesicle" (*u.v.*) is quite free from the projecting head of the embryo; a clear watery space intervenes between the two parts, and this space is larger on each side of the flat head. Two principal strata of the blastoderm are seen above this space, and between them another shallow transverse vacuity, the mouth.

The anterior cerebral vesicle (*c.* I) is full of a gelatinous fluid, but its more condensed peripheral part is very soft and of no great extent; it is somewhat grooved below. Below this shallow sulcus, in the tissue between the membranous cranium and palatal skin, there are seen the sections of two chondrifying bands, and in the sulcus between the eye and brain a thickening of a triangular form is observable; this is softer still. The inner pair are the trabeculæ in section, and the outer the subocular or palato-pterygoid bars. In the thin "hammock," with its thickened middle part, which is swung at a small distance below the space of the mouth-cavity, there is a more solid but flat pair of sections; these are the outspread ends (see also fig. 7, *mn.*) of the first postoral rods, their symphysial ends. So that we have here, beneath the first cerebral vesicle:—1st, a capsule; 2nd, a layer of "mesoblast," containing the cartilaginous rudiments of the first and second præorals; 3rd, a layer of enderon (palatal); 4th, below the oral cavity two layers of epiblast and one of mesoblast, this latter containing the first postorals or third facial arches. A section from the same part in a more advanced embryo, or near to the second stage, shows a great change (Plate II. fig. 1); here the section, which is through the very middle of the exposed and hidden eyeballs, is also posterior to the "prosencephalon" and through the middle of the "thalamencephalon;" their imprisonment has strangely hindered their symmetrical growth, but they have acquired much substance; we are here *behind* the cavity of the prosencephalon, and in front of the next, and therefore in the most solid part of the brain. The left half of the "thalamencephalon," like the left eye and the left half of the "hemispheres," is smaller than the right. The more solid tissue of the first, second, and third arches is shown in section, and the flattened Meckelian region is well displayed at the symphysis of the chin. A glance at this figure and the last, for comparison's sake, will show how fast the differentiation of layers has taken place; but that which is of most importance to notice is that a new cavity has been formed, the "anterior palatal recess" (*a.p.r.*). This marked splitting-up of the facial strata divides the mouth from the layer in which the trabeculæ and subocular rods are imbedded, and is well seen in older embryos as a recess between the upper (trabecular) palate and the "naso-frontal process" (see Fourth Stage, Plate II. fig. 10, *n.f.p.*, *a.p.r.*).

The next section (Plate I. fig. 11) is through the fore part of the *right* ear-sac, but the obliquity of the head makes even this *true* transverse section miss the *left*; it is in front of it, and also of the notochord. In this stage the eye- and ear-balls overlap each other, and hence a section which barely escapes the eye takes off the fore part of the ear. The brain is here somewhat more developed than in figs. 8 & 10; but the razor passed through the more solid cerebral substance which lies immediately behind the thalamencephalon, in front of the pituitary body, and across the overhanging fore edge of the "mesencephalon." The razor missed the "subocular" boss on both sides, whilst the trabeculæ, the mandibular bars, and the *right* hyoid were cut through *obliquely*. On the left side the umbilical vesicle is free, but on the right it is continuous with the blastoderm beneath the hyoid bar. At this point three things are clearly seen—the fore face of the auditory sac is chondrified, its outer part being pitted by the anterior canal, the hyoid bar has crept beneath this region, and the "primordial auditory involution" lies over the supero-external region of the sac; it is here cut through its middle. If this be compared with the other figures, especially figs. 2, 3, & 6, it will be seen that the naked upper part of the labyrinth lies just within the primordial opening in the skin. Hence I infer that the "labyrinth" itself has been constructed out of that layer which was primarily uppermost, the "epiblast," and that the next layer within, the "mesoblast," may be credited with the formation of the cartilaginous shield.

The last of these sections (Plate II. fig. 2) belongs to the very close of the first stage, and is much in advance of the last; it is also from a point further back, although the broad hyoidean band has been displayed. Here the "epencephalic" region is cut through, the third vesicle, and the medulla oblongata; the apex of the notochord and of the "basilar plate" and the fore part of the "labyrinth" with its "shield" are severed; these parts have now coalesced beneath the rudimentary "sacculus." This band is a "connective" passing in front of the "inferior fenestra" (fig. 4, *fs.o.*); it is very thin. On account of the natural obliquity of the parts, the first and second branchials are shown with their basal piece; they are prematurely distinct in this specimen; for I find them less specialized in others, which in other respects are more advanced*. The hinder part of the mouth here must still be "epiblastic" as to its lining, for it is in free communication, by the visceral clefts, with the outer skin.

Second Stage.—Unhatched Salmon with hyoid arch splitting up.

Notwithstanding the fundamental identity of the morphological plan of growth in Vertebrate embros, the detail is marvellously varied, and these variations take place very early; both the *precocity* and the *amount* of these variations, especially as seen in this and my former subject, the Frog, have surprised me again and again. The light obtained from *that* has indeed been useful for *this*; yet not as a clear, flooding light, but merely as a lantern to my first steps.

Therefore this piece of research has been made with a greater sense of comfort and confidence, but not with less caution and care. The manner in which the second postoral arch is, as it were, chopped and split into fragments is very unlike what I have described in the Tadpole; and more, it gives as yet little promise of becoming a "Teleostean" hyoid apparatus. The three foremost arches have not changed much, they are quite unsegmented; but the second "postoral" (Plate II. fig. 3), besides having its foreturned lower extremity cut off and rounded into a globular submesial joint, has been

---

* The reader may think that I have drawn a little upon my imagination for the deep yelk-bed in which the auditory region is made to lie in this figure, and for the awkward manner in which the chorion is made to compress the young cerebellum; all I can say is that the actual object, uninjured in relation, although shaven through, appeared as strange to me.

cleft from apex to base into a broad anterior and a narrow posterior band. The round distal piece belongs rather to the extremity of the former than to that of the latter; thus the front division is connected with the azygous "lingual" or "basihyal" piece by this distal segment, the "hypohyal." It is useless looking to the Tadpole for an explanation of this; and as we shall soon arrive at a "Ganoid" stage, we may do well to look among the "Plagiostomes"—that is, we must search a lower morphological level.

In the Brazilian Torpedo (*Narcine*)* there are two bars in this region, the foremost, however, being slender and the other broad (see MÜLLER's 'Myxinoids,' pl. 5. figs. 3 & 4, *a.d.*). In my last paper (p. 195) I ventured to call the foremost bar a "metapterygoid," much wondering why it rested upon the broad hyoid suspensorium. I retract; it is quite *behind* the mandibular region, and the two together are surely the split-up second postoral, the anterior a feeble "hyo-mandibular," and the posterior a massive "cerato-hyal;" there is no "hypohyal," as far as I know, until we get to the "Ganoid" Sturgeon.

In the higher groups we have long been pestered with two cartilaginous and bony tracts on each side in the substance of the second postoral arch; hence the misunderstanding of the relations of the "incus;" this element may now be said to be safely fixed in its own place as the "antero-superior segment" of the split-up hyoid arch, and the mammalian representative of the Fish's "hyo-mandibular."

The "basihyal" (Plate II. fig. 3, *gh.*) has now become a thick lozenge-shaped mass of cartilage, strongly wedged between the "hypohyals." This preparation, which has been flattened out for display, shows considerable modification in the form of the mandibular bars; they are more strongly sigmoid, and the "orbitar process," above the abrupt bend, is very distinct; its most definite reappearance is in Chelonians and Birds. The thick "subocular" flap is acquiring a more solid palato-pterygoid pith; towards it, in front, the still small and distinct trabeculæ (*tr.*) are sending a small connective lobe, the first rudiment of the "ectoethmoid" with its "superpalatal" facet. The same stage is illustrated by the figure of an *uncompressed* specimen (Plate II. fig. 4), from which the postoral part of the face has been removed to display the auditory sacs from below. The oldest specimen of the first stage (Plate II. fig. 2) may illustrate this, which is but little older; here (fig. 4) the "notochord" is twisted to the left side and projects beyond the ear-shaped flaps that form the end of the "investing mass." Behind, these moieties contract, first suddenly and then gradually, growing to a point as they form the "basioccipital" region. The primordial "fenestra ovalis" notches both the prootic cartilage and the investing mass, and with the help of the two secondary isthmuses a very elegant circular window is left; not through it, but a little externally, the otolith may be seen shining through the cartilage. The anterior, horizontal, and posterior canals have bulged out the cartilage in their respective regions; above, there is still a fenestra over the posterior canal; this is not closed for some time to come (see next stage, fig. 7, *ep.*). Between the investing mass and the ear-sac in front there is a deep notch; into this the trabecular apex is creeping. Another head at this stage has supplied me with the most lucid appearance of the relation of the investing mass to the trabeculæ. These translucent Salmon-embryos show their parts with intense clearness, and here especially a definite image is important. This individual had broader trabeculæ (fig. 5, *tr.*) and investing mass with narrower ends than others examined; the knee-shaped trabecular apices, bent before the pituitary body was within shot-range of them, turned inwards, and lay crosswise *upon* the free ends of the investing mass, overlapping them unconformably.

---

* Professor GEGENBAUR in the recently published third part of his 'Untersuchungen.'

The blades of these minute "forceps" evidently move, opening as they grow, and bring themselves into conformity to and into coalescence with the ends of the investing mass; this will be seen in the next stage.

Third Stage.—Unhatched Salmon with MECKEL'S *cartilages free.*

This stage does not yield in interest to the last, and the growth now must be very rapid, the metamorphic changes taking place as fast as the development of flowers in spring time.

I think it is very probable that the third stage is the morphological equivalent of that which is persistent in the Rays, just as in the unhatched *chick* we come upon "Rhynchosaurian," Struthiine, and Tinamine stages, as we delve from above downwards into the more simple and unspecialized conditions of the embryo Fowl. Certainly I shall soon come to a most evident "Polypterine" stage. Standing on the level of those depressed outspread "Elasmobranchs," the Rays, we see what fitnesses for aquatic life may arise in organisms halfway between the simplest possible conditions of a Fish and the noblest spiny-finned "Percoids." If these flat-headed, flat-bodied, long-tailed, broad-flippered Salmon-embryos had grown largely without *zoological improvement*, to the Plagiostomes they must have gone, no other place would have been found for them *.

One of the first preparations made by me of the Salmon-embryos was that which is figured in Plate II. figs. 6 & 7. This preparation of the primordial skull was very exquisite, but showed such strange characters that it had to wait for some weeks for interpretation; the second stage, just described, was the *sine quâ non* for that. Articulated to the fore and under part of the well-developed periotic capsule, I found *two* similar, nearly equal, strong cartilaginous rods, each growing athwart, under the head, and only directed slightly forwards. The foremost was *too far back* for it to be the mandibular pier, and they both were too well developed, too large, and too far forwards and outwards to answer to the first and second branchials. Thus in a few moments I was able to reason out what they were not; the missing link (my second stage, fig. 3) turning up, it soon became evident what they were. Yet this temporary conversion of the second "postoral" into a "double couple" of arches disturbed the complacent manner in which I was making the subdivision of the Tadpole's facial parts into a measure for the rest; the structures seen in that type are not the most perfect, but are low in kind, and therefore cannot be

---

* Those of my earliest stage, in which the non-symmetry is at its least degree (Plate I. fig. 10, *transverse section*), have the Raiine type of head in perfection.

used as a rule. Yet this lesson was learned from the Frog—namely, that part of an arch being segmented off from the primary bar may *travel up* or *travel down* just where the specializing force pleases; the "hyoid cornu" of the Frog travels up, that of the Osseous Fish travels down. The anterior division of the second postoral in the Salmon now stands forwards and touches the first postoral arch (*hm.*, *q.*); it has left its own distal segment, the "hypohyal" (*h.hy.*), to the hinder moiety, which moiety is still articulated like the fore piece, by a flattened hook, to the ear-capsule; the "basihyal," or *tongue piece* (*g.h.*), still keeps its relation as the keystone, and still projects forwards considerably.

But that which marks this stage is the segmented condition of the first "postoral" or mandibular arch (compare Plate II. fig. 3 with figs. 6 & 7). In this simple morphological process my former subject failed for interpretation; *there*, in the Tadpole, the *pier* is of extreme length, so long as to carry the "orbitar process" in front of the eye; but the free Meckelian arch is for some time very small indeed (*op. cit.* Plate III. fig. 12, and Plate IV. figs. 7 & 8, *mk.*); and although it *acquires* the sigmoid bend and the "angular" hook, yet at the first it is a mere *bud* pinched off, as it were, from the lower end of the bar, which before segmentation (*op. cit.* Plate III. fig. 3, and Plate IV. fig. 1, 2, *mn.*) is strongly inturned below. Here there is something very *chirurgical* in the way in which this segment is "cut out without hands," the invisible knife passing now across, now along, and then dexterously slanting through, so that a *ball* is formed on the upper part, and a *cup* and a long rounded angular process on the lower. This specimen is of the *short-jawed* variety (compare Plate I. figs. 1 & 3), and MECKEL's cartilages pass athwart and then curve backwards, perfectly *Ray-like*. Already the pier of the mandibular arch is escaping downwards from its original position, and has grown very little since the last stage, and, in this specimen at least, the orbitar process is less marked. If the position of this pair of cartilages be considered, it will be seen that they well illustrate the so-called palatal cartilages ("Gaumenknorpel") of *Narcine* (MÜLLER, *op. cit.* plate 5. figs. 3 & 4, *c*) and the azygous palatal cartilage ("unpaariger Gaumenknorpel") of the Sturgeon (*op. cit.* plate 9. figs. 10 & 11, *b*). It is the *top part*, the inturned outspread apex of the arch, which is segmented off in *Narcine* on each side; in *Acipenser* it is evident that these segments early coalesced to form the "azygous metapterygoid"*. It is perfectly normal that the facial arches should *turn in* and flatten out at their apex; those the least specialized, the gill-arches, constantly do this, and the substitution for gill-papillæ of small teeth is a very gentle change and superaddition of function. Certainly the foremost arches are subject to most modification; but even the outbowing of the trabeculæ is perfectly normal, and their hooked apices only enclose the pituitary body because of its contiguity; the hooking was a morphological fact before any such relation was brought about by specializing growth. As to the segmentation of the mandibular arch in *Narcine* and *Acipenser*, let the reader compare their metapterygoid segment, just referred to in MÜLLER's work, with his plate of the *Chimæra's* skull (*op. cit.* plate 5. fig. 2, *qqq*), and see how in that type the "pharyngo-branchials" are segmented off to form outspread, smooth, arched roof-plates to the pharynx; thus the order, harmony, and *simplicity*

---

* See 'Monthly Microscopical Journal,' June 1873, plate 20. figs. 1, 2, 5, *mt.pg.*

of the whole matter will appear to him. As to the languid, feeble, tardy-growing "sub-ocular" bands, these are not really chondrified in this the third stage; they are, however, larger. But the trabeculæ have grown immensely (Plate II. figs. 6 & 7, *tr.*). Looking at them in this stage, before they have done more in relation to the cranium than to marry themselves to the "investing mass," we shall see how facial arches must be modified that have to grow in a directly horizontal manner, adapting their apex to some convenient fastening-point behind. Save in the lack of segmentation of the out-bowed part, these trabeculæ at this stage are very exactly like the next pair (the palato-pterygoids) of the Pelecanidæ, of *Sula* and *Phalacrocorax* at present, and of *Pelecanus* itself, as soon as they have combined and sent upwards a common crest; the divergence of the pterygoids in these and other Birds is the true morphological equivalent of the divergence of the trabecular apices outside the pituitary space.

We have seen already that the trabeculæ at a very early stage (Plate I. fig. 5, *tr.*) have their leafy ends bilobate; the outer lobe is the first morphological germ of the "ethmo-palatine;" it, in reality, is a conjugational "stolon" from the minute trabecular stem. Already, in a very few days, the trabeculæ have grown tenfold; they have also articulated, as facial arches are wont to articulate, with their successor bars; and now we have the junction of the ascending part of the palatine with the "lateral ethmoid," never to be seen wanting again in our long ascent to Man. Underneath (fig. 6, *tr.*) the ethmoidal region is transversely ribbed: these *ribs* grow out afterwards as the pedicles (the serial counterparts of the "basipterygoid processes"), to which the palatines are suspended. In front the other lobe meets its fellow; it is thick, and the two diverge at a large angle; they together form the rudiments of the nasal septum and the "subnasal laminæ." Above (fig. 7, *tr.*) the "ectoethmoidal" wall is quite soft; it separates the nose from the eye: the whole of the cerebral roof is also quite uncartilaginous.

The original membranous space below the primordial ear-opening is now a small fenestra over the posterior semicircular canal (fig. 7, *ep.*); the "fenestra" in the periotic floor (fig. 6, *f.s.o*) is less; moreover, the whole capsule, now well united to the investing mass, has developed considerably since the last stage. Now the occipital arch (*b.o.*, *e.o.*) can be seen behind the auditory capsules; but the two divisions have not united above; they are nearer, however, than the figure (7) would indicate, as it is a little outspread for display.

The branchial arches do not grow at the same rate in different individuals; they are more differentiated in the oldest of my first stage (Plate II. fig. 2, *br.*) than in those examined in this, the third. Here (Plate II. fig. 8) these elegant blunt hooks have coalesced by their lower straight end, and the coalesced part is turned backwards, swollen, and half cut off as a median piece. This is similar to what I found in the formation of the sternum in the embryo ox ('Shoulder-girdle and Sternum,' plate xxix. fig. 1), where the median piece is made out of the ends of the lateral pieces. In the hyoid arch of the Salmon (Plate I. fig. 7, *g.h.*) the median piece is truly and *primarily* azygous; here, in the branchial arches, it is a *secondary* azygous element, made up of the coalescing ends of a pair of rods. As yet there is no basal piece behind the third arch. There is now no appearance, nor will there be for several days to come, of any further subdivision of the branchial arches; their respiratory papillæ are beginning at this stage as *dermal* growths. With the "primitive groove" filled in, with considerable consistency of the brain, and with the skeletal growths so far advanced, the young Salmon is becoming too active and strong for further imprisonment.

Fourth Stage.—Salmon-fry in the act of hatching and newly hatched.

The figures given are from young Salmon with the head only protruding from the shell (Plate II. figs. 9 & 10, and Plate III. figs. 1–3), and of others which had enjoyed a day or two of freedom (Plate II. fig. 11, and Plate III. figs. 4–6). The expansion of the cerebral vesicles is a correlate of that peculiar bend downwards of the fore part of the head which is called the "mesocephalic flexure." Now, for the first time, the head assumes the form so familiar to the embryologist in the air-breathing Vertebrata. This overbending of the cerebral vesicles evidently is not the *vera causa* of the arrest of the notochord behind the smaller, dipping vesicle, the pituitary body, but is a correlate of the sudden finish of the investing mass: a cause for both these arrests has yet to be found. This, which may possibly be a modification taking place during long secular periods, is also correlated with the small amount of independence seen in the cartilaginous cranium, which, where it is not largely aborted by the implantation of the ear-bulbs, yet grows over the membranous cranium from any neighbouring cartilaginous tract. I said *grows over*, that is in the lower types; but the most important part of the nervous system is largely roofed in simply by investing bones. As yet, in this fourth stage, the only part of the membranous cranium floored or surrounded by cartilage is the "medulla oblongata." A sectional view, both during hatching (Plate III. fig. 3) and after (fig. 5), shows the form of the principal parts of the brain, and the relation of its parts to *axial* and facial structures. The earlier specimen (fig. 3), even, has now budded out a well-defined "prosencephalon" ($C\,1^b$), the more solid "thalamencephalon" ($C\,1^a$) lying on a pair of balks, which are the bent and flattened trabeculæ (*tr.*): the pituitary body (*py.*) has no "rest," but lies between the trabecular hooks, amidst gelatinous blastema. Even the fore part of the "medulla oblongata" (*m.ob.*) rests upon a fold of the primordial enclosing membrane, which retires to line the back of the pituitary body; this is where RATHKE placed his "median, or azygous trabecula," evidently a mere membranous band projecting beyond the notochord in the mid line, and having no morphological relation to the trabeculæ proper: even these parts were misunderstood by this most excellent embryologist. If these sections be compared with the earliest stage (Plate I. fig. 8, *nc.*), a notable difference will be seen—namely, that the pointed end of the notochord has retired somewhat, and that the apex of its sheath has grown downwards behind the pituitary body as a free tongue-like process.

In these sectional views we see how the walls of the face are broken into ridges and furrows; and in fig. 5 especially the relation of both the præorals is shown—the second (subocular) forming the upper cheek-wall, and the first (the trabecular) forming a curved beam on which the first vesicle rests. The trabeculæ end in and fill the cavity of the "naso-frontal process," which ends below and behind in a free lip—the *floor* of the "anterior palatal recess" (see also Plate II. fig. 10, *a.p.r.*). In the section of the more advanced specimen the "subocular" (pterygo-palatine) rod is brought into view; between it and the trabeculæ there is seen the bulging orbital floor (see also Plate II. fig. 10, and Plate III. fig. 2, *or.*). Here, under the eyeball (see also Plate III. fig. 4, *l.cl.*), is a *cleft*, which I find very distinct, and which Professor HUXLEY shows me is the "lacrymal cleft;" it is the true *first cleft*; the oral opening is the second, and therefore the tympano-Eustachian, or first postoral, is the third. This cleft is also important as stamping the true visceral-arch character upon the two præorals. When arches can be shown me which combine the characters of *ribs* and *visceral arches*, then I will treat of them as morphological *varieties*; *species* they are, to all intents and purposes, being altogether independent of the *perineural* axis—most largely developed when furthest in front of it, and excluding the heart instead of containing it. The trabeculæ at the time of hatching are solid, so also are the first and second postorals; but the chondrification of the pterygo-palatine and branchial arches is tardy, and they still contain a central cavity filled only with protoplasm (see Plate II. fig. 10, *p.pg.*, and Plate III. fig. 3, *br.*). Morphologically, we are now at the level of the "Chondrosteous Ganoids;" a familiar example, happily extant, is the Sturgeon. Now in the life-history of this Teleostean we for the first time see the "stylo-hyal," and the Sturgeon, standing above the Plagiostomes and below the higher Ganoids, shows it for the first time, zoologically. Even in the second stage the Salmon has gone beyond the Plagiostomes in having segmented off a "hypohyal; in this it agrees with the Sturgeon, which, however, has its own specialization in the complete subdivision of the first half of the second postoral, the "hyo-mandibular." Even at the time of hatching, the first postoral cleft is being obliterated, but the cutis being removed, it can be seen as an opening undergoing division into *two*: the lower of these is the tympano-Eustachian, and is entirely occluded by the symplectic; the upper part remains open in most Plagiostomes and Ganoids as the "spiracle." The amount of metamorphosis which takes place before the fry has fairly escaped from the egg is evident (see Plate III. figs. 1 & 2); for almost all the essential characters of the Teleostean face have already appeared. The most remarkable of these are the low position of the first postoral (*mt.pg.*, *q.*), the equally low position of the posterior division of the second postoral (*c.h.*), the appearance of the little connecting segment (*st. h.*), and the development of the *halved hook* of this, the hyoid arch, into the backwardly turned massive head of the "hyo-mandibular" (*h.m.*). Moreover the individual segments have not only gained their new relationships, they have also acquired very nearly their permanent form; for the muscular masses are now developed, which have their origins and insertions in harmony with the nature of this type of Fish.

The huge eyeballs still obscure the morphology of the upper part of the face, and their sockets especially, at present over large (see Plate II. fig. 10, and Plate III. fig. 2, *or.*), widely sever the pterygo-palatines and their *cleft* from the trabeculæ.

The former (*p.pg*) are still distinct from the quadrate (*q.*) with its projecting "orbitar process;" the "metapterygoid process" is blunt and short, and has not the flattened shape it afterwards assumes. The "hypohyal" has now well applied its hollow upper end to the rounded base of the "cerato-hyal" (*c.h.*), and the "basihyal" is seen to be the first of a series of azygous cartilages, which serve to all but the last abortive branchial as key-stones. The ascending and lessening branchial arches are becoming stout, and are developing their respiratory papillæ and their alternating *cogs* that convert the gill-arches into a *colander.*

A bird's-eye view of the primordial skull of a recently hatched Salmon (Plate III. fig. 6) shows the advances just spoken of as having been made since the third stage. Even now, over the posterior canal, the cartilage is deficient; the fenestra is a remnant of the great space beneath the primary infolding of the "blastoderm."

Fifth Stage.—Salmon-fry of the second week after hatching.

This stage does not yield in interest to any going before or after it; taking it for all in all the skull has now the most perfect parallelism with that of the culminating "Ganoids," such, for instance, as the *Polypterus.* In that light I have seen it, and know not well how to describe it otherwise than by using a running comparison with what is seen in that fine waif of the seas of the primary epoch. Two of our chief experts in the "Ganoidei," namely Professors Huxley and Traquair, are of one mind with me in this view: they both see the Ganoid type in this plane of the Salmon's *ascending* growth, and thus there are three witnesses to attest to the truth of the matter.

If the reader would follow me in the details of this stage, he should keep open before him Dr. Traquair's "Cranial Osteology of the *Polypterus*" (Journ. of Anat. and Phys. vol. v. pl. 6). In this condition of the Salmon's skull there are no ossifications of the cartilage; the great *first bone*, the parasphenoid, has appeared, and, as in the lower Ganoids, is of huge relative size; it reaches from between the nasal sacs to beneath and behind the auditory (see it in dotted outline in Plate IV. fig. 3, in longitudinal section fig. 4, and in transverse section fig. 7, *pa.s.*). The "supraethmoidal plate" (fig. 4, *eth.*) has appeared as a fine film of bone in the thickness of the subcutaneous stroma, and the frontals (Plate III. fig. 9, *f.*) are styloid ossifications, forming eaves to the low cranial roof. The thickened stroma below the trabecular cornua is not ossified into the "vomer;" several, however, of the parosteal and ectosteal tracts of the face are already present, and will soon be described. What I have to draw the attention to principally, is the greatly altered state of the primordial (cartilaginous) cranium; the ossifications are of secondary importance. A comparison of the skull as it existed a week before (Plate III. fig. 6, *upper view*) will show the *rate* and the *degree* of metamorphic change which has to be contemplated now.

Even now the membranous cranium is growing upward, free of the fore face substructure; the whole of the inflated brain-sac, very large in relative size, as yet, may be studied in its own morphological independence. The trabeculæ, stretched forward under it, like the arms of a swimmer, have already coalesced, and send their outspread palms beneath the nasal sacs, to which they form a floor, as well as serving in this complex building the purpose of beams to the brain-chamber and rafters to the palate*.

Nothing, perhaps, in the whole Vertebrate morphology has such a vegetative freedom of growth into branch-like and leafy outgrowths, spreading outwards and reaching far forwards, as the first facial arch. Yet it is upon the trabecular modifications that the very *facies* of the types largely depends; the Shark, the Sawfish, the Skate, the Tortoise and the Bird, the Whale, and even Man himself, all these largely owe their "prognathism" or their "orthognathism" to arrest or extension of the trabecular growths. Here, as in the *Polypterus* (TRAQUAIR, *op. cit.* plate 6. figs. 2 & 3), the muzzle is broad and depressed, owing to the great outgrowth of the early two-leaved end of each trabecula. *Upon* the coalesced "cornua" (Plate IV. fig. 2) there has arisen an elegant X-shaped rudiment of the median ethmoid and nasal septum in one. Between the hinder legs of the X is seen an opening (shown also *from behind* in Plate III. fig. 7); this deficient fusion of the two sides thus preserves the counterpart of the Lamprey's nasal opening (MÜLLER, *op. cit.* plate 4). On each side of the median upgrowth we see the "subnasal lamina" (figs. 1–3, *s.n.l.*), on each side of the snout the divided "upper labials," and outside the ethmoid the articulation of the palato-pterygoids (*p.pg.*). The X-shaped "mesoethmoid" (ossified in *Polypterus*, see TRAQUAIR, figs. 1–3, *E*) is continuous with the shelving, inturned "ectoethmoid" (Plate III. figs. 7 & 8, *l.e.* 1); these growths, hard to be understood, are continuous below with the pedicle for the palatal facet (Plate IV. figs. 1–3, and Plate III. fig. 7). Where the olfactory crura escape in front to ramify on the nasal sacs (Plate III. fig. 8, 1), there the ectoethmoid can be seen to be continuous, below, with the outspread "trabecular cornua" ("subnasal laminæ"), and above to have a mutual bond in the *new* cranial roof over the "prosencephalon" (C 1^b). In the transverse section through the nasal sacs (Plate III. fig. 7, *ol.*) the commencement of the sloping roof is, of necessity, cut through obliquely; but its structure and meaning cannot be misunderstood if it be looked at in the *dissected* and *bisected* skull (Plate IV. figs. 1–4). This elegant roof has no *side walls* to support it; it is, as it were, thrown like a *tarpaulin* over the brain-sac (see also Plate III. fig. 9), and is tied by cartilaginous ropes, behind, to the walls of the ear-chamber. Where this structure is cut through at its convergence in front (Plate III. fig. 8) we have a *cincture* of cartilage (see Dr. TRAQUAIR'S remarks, *op. cit.* pp. 170, 171), similar to that which is seen in the Frog ("Frog's Skull," Plate VII. fig. 9).

This ethmoidal "tentorium" contracts and thickens to form the part which in the adult

---

* We must be very cautious of interpreting *continuity* of even cartilaginous structure as necessarily indicating morphological simplicity. Here, in the Salmon, the cranium is free from the trabeculæ as it is not in other types. We must keep also an expectant watch for the solution which may turn up of the *after division* of the skull-segments and ear-organs of the Mammalia; in that class there seems to be a reversion to even a Myxinoid type of structure, for the nasal sacs, growing backwards under the skull, divide the trabecular base from the proper cranial floor.

I have termed "culmen cranii;" *then* it stretches backwards as far as to the occipital cincture; *now* it covers only the first and part of the second cerebral division (Plate IV. figs. 1 & 4). The "great fontanelle," which in the adult is covered in and reduced to two small lateral rudiments over the postsphenoidal region, is now a most elegant heart-shaped and large space (Plate IV. fig. 2, *fo.*), through which, in the dissected skull, half the basal region can be seen. Even in the adult Frog ("Frog's Skull," Plate IX. fig. 6, *fo.*) there is as much open space, for it reaches further forwards, although more covered in behind. If it be well considered, this expanded fontanelle of the young Salmon is essentially like that of the adult *Polypterus* (Traquair, *op. cit.* plate 6. fig. 2), which is bounded by a limiting cartilage that runs behind into the postfrontal part of the ear-sac; this cartilage is like a *wall-plate* which has had part of the roof removed from it above, and part of the wall taken from beneath it. The creeping backwards of the ethmoidal "tentorium" at the mid line causes the emargination in front of the fontanelle; and each "funis tentorii" is continuous behind with the sharp cartilaginous crest that arises as an upgrowth from the auditory sac, subparallel with the elegant curve of the "anterior semicircular canal." Reference to the profile view of the skull (Plate IV. fig. 1) will satisfy us that we have in this peculiar band the cartilaginous pith of that remarkable "supraorbital bar," which I have described in the first stage (Plate I. figs. 1, 2, 3, 4, 6, 7, *s.ob.*), which stretches from the nasal to the auditory sac. On account of their origin in the early embryo they may be called the "supraorbital bands" (*s.ob.*); they have no distinct counterpart in the Frog or Fowl, but the retral part of the roof has a very evident counterpart (see "Fowl's Skull," Plate LXXXIII. figs. 2, 4, 5, *growing backwards from eth.*). But the roof-cartilage is well developed in Birds generally; in the "*Struthionidæ*" it is ossified separately from the "pars perpendicularis" ("Ostrich Skull," Plate VIII. figs. 3 & 10, *eth. p.e.*), whilst in the Cassowary (ibid. Plate XIV.) it is enormously developed, and becomes the well-known "helmet." I need scarcely mention the free roof-growth in Sharks, both ordinary and "Chimæroid," and also in the Sturgeon.

Returning to the "trabeculæ," we find that they gradually narrow backwards towards the pointed apex of the cordiform pituitary space; they thicken as they become narrow, and elbow out strongly before they apply themselves to the upper surface of the now rounded apices of the investing mass, from which they were very distinct in the specimen figured.

The pituitary body is let down through the cranial floor (Plate IV. figs. 2–4, *py.*) on to the subcutaneous parasphenoid; but it occupies very little of the open space, which is further enlarged by free communication with the "posterior basicranial fontanelle" (Rathke), the gap in which the apex of the notochord lies. To this latter space the orbital muscles (figs. 2 & 3, *o.m.*) converge and lie (see Plate V. fig. 1, *o.m.*) upon the parasphenoid; at present there is no "prootic bridge" covering them above; the apex of the notochord lies upon their "raphe." The "investing mass" (*i.v.*) is now largely confluent with the auditory masses; in front each moiety is separated from the prootic region by a rounded notch, and behind each side is developed into two lips; those below become the basioccipital articular ring, and those above the zygapophyses for the first cervical vertebra. Sectional views (Plate III. fig. 11, *behind*, and Plate V. fig. 5, in *front*) show the increasing thickness of the basilar plate from before backward. The lateral and superior parts of the occipital cincture are everywhere continuous with the related parts of the periotic capsules (Plate IV. figs. 1 & 2): these structures are peculiarly elegant at this stage, as the cartilage only thinly veils the curves and swellings of the membranous labyrinth, which, like the brain (fig. 4), is now very large relatively. The apertures for the hinder division of the fifth nerve (the front division escapes over the notch), the "portio dura" of the compound seventh, and the "vagus" and its companion, these can be seen piercing the periotic walls (figs. 1–3, 5^b, 7^a, 8). Above (figs. 1 & 2) a gentle sulcus separates the growing roof from the elevation caused by the anterior and posterior canals; the latter, swelling out behind, form the "epiotic" eminences. The most projecting part laterally is formed by the horizontal canal, and under it (fig. 3) is the ridge, which sets bounds externally to the facet for the extended head of the hyo-mandibular (figs. 1 & 3, *h.m.*). In the middle of the under surface the skull-base is swollen into an oval eminence on each side, and the cartilaginous part of this swelling is deficient outwardly; here still lingers the primordial "fenestra ovalis;" and mesiad of this the cartilage is very thin (Plate V. fig. 5), for here is the "sacculus" with its "otoliths." In front the auditory sac grows into a laminar form, and this thin edge gradually narrows as it passes above into the "supraorbital band;" this ingrowing lamina becoming much more developed forwards, gives rise to the "alisphenoid," which is distinct neither from the band above nor from the ear-sac behind; it is some distance from the investing mass. There is at present no rudiment of even the very rudimentary "basisphenoid" of the adult. The whole of the "anterior sphenoidal region" is membranous at this stage (Plate IV. fig. 7, *o.s.*). A description of the sectional views, although involving some recapitulation, will serve to make the description clearer. A longitudinal section (Plate IV. fig. 4) shows that the roof-cartilage growing back from the ethmoid only lies over the fore part of the "mesencephalon" (C^2); anteriorly the "mesoethmoid" ends abruptly over the nasal sacs; over this part the thin "superethmoidal" lamina of bone (*eth.*) is seen. The nasal sac (*ol.*) lies upon the "trabecular cornu," and to it the olfactory crus (1) is passing; it pierces the antorbital wall. In front of the trabecular horn the "premaxillary" (*p.x.*) is cut through. The trabecular floor (*tr.*) is continued to beneath the "thalamencephalon" ($C\ 1^a$) and then diverges: the pituitary body (*py.*) is seen in front of the notochord (*nc.*). Beneath the trabecula is seen the thin parasphenoid (*pa.s.*), but not the "vomer;" this antecedence of the former bone brings this stage to a level in this respect with *Lepidosiren*. Part of the "cerebellum" (C 3) is covered with cartilage, the "superoccipital" (*s.o.*); the medulla oblongata (*m.ob.*) lies on the notochord. But the "prosencephalon" does not lie upon the trabecular floor; it rests upon the wings of an "interorbital septum" (*i.o.s.*), which is at present entirely membranous. A more enlarged view of the middle of this section (Plate IV. fig. 5) below shows the orbital muscles passing beneath the notochord on each side of the pituitary body (*o.m.*, *py.*, *nc.*); this lobe does not yet reach the parasphenoid. A section like the fore part of the last (fig. 6), but to the right of the mid line, shows the opening of the nasal sac (*ol.*), the inner face of the eyeball (*e.*); the "ectoethmoidal," or antorbital wall, is cut through external to the roof, and is seen articulating with the palato-pterygoid bar (*p.pg.*), in front of which is the principal upper labial (*u.l.*″); the premaxillary (*p.x.*) is cut through, and the upper jaw is seen from the inner side. The first and second transverse sections (Plate III. figs. 7 & 8) have already been spoken of; in the latter the forks of the parasphenoid (*pa.s.*) are cut through, and in the first it is severed in the vomerine region. In the third section (Plate III. fig. 9) the "prosencephalic" lobes are cut through; and this part of the membranous cranium is roofed over by the ethmoidal "tentorium," the free edges of which are bound down by the styloid "frontal" (*f.*). The cranial walls pass down into the "interorbital septum" (*i.o.s.*), which is continuous below with the perichondrium of the tilted and coalesced "trabeculæ" (*tr.*). The parasphenoid here is arched and outspread laterally, in accordance with the lower surface of the trabecular floor. The huge eyeballs (*e.*) are separated by copious gelatinous tissue, keeping the olfactory crura (1) from the septum, which is here at its highest. The fourth section (Plate IV. fig. 7) is through the "thalamencephalon" (C 1″) and the fore part of the "mesencephalon" (C 2), on each side of which the *tent-ropes* ("superorbital bands") (*s.ob.*) have been severed behind the rudimentary frontals; as this section is through the eye behind the entrance of the optic nerve and in front of their exit from the cranium, they are seen in section here (2) near the lowered interorbital septa. The trabecular floor is flatter here, and so also is the parasphenoid which underlies it (*tr. pa.s.*). The fifth section (Plate III. fig. 10) is very instructive also; it is through the middle of the "mesencephalon" (C 2), the fore part of the pituitary body (*py.*), the most diverged and terete part of the trabeculæ (*tr.*), the back of the orbit (*or.*), and cuts through that part of the "superorbital band" (*s.ob.*) which is passing insensibly into the auditory sac, its "sphenotic" region; a downward growth from this part of the cartilaginous skull gives rise to the "alisphenoid." The exquisite infoldings of the parasphenoid (*pa.s.*) are here seen in relation to the pituitary body, exactly between the elbowed trabeculæ (*tr.*). The sixth section (Plate V. fig. 5) has been already partly described; it exposes the arch of the anterior and the ampulla of the horizontal semicircular canals, the "utriculus" and the "sacculus;" it shows the deficiency of the cranial roof at this place over the "cerebellum," and the huge size of the medulla oblongata (C 3, *m.ob.*). The seventh section (Plate III. fig. 11) is through the basioccipital, just missing the supraoccipital roof; it passes through the medulla oblongata (*m.ob.*), close behind the cerebellum: running askance, the razor has opened the ampulla of the left posterior canal, and has laid bare the canal through which the compound eighth nerve passes (*p.s.c.* 8). This section is from a less advanced specimen than that illustrated in figs. 2 & 3; the other structures severed in these sections will help to explain the movable machinery of the mouth and throat, which must now be described. In the profile and bird's-eye views of the primordial skull at this stage I have purposely excluded the delicate ectosteal laminæ, many of which had commenced; but the relation of these can be best shown in the transverse sections, and my most important morphological business is the description and interpretation of the cartilaginous basketwork.

In Professor HUXLEY'S Croonian Lecture (Proc. Roy. Soc. Nov. 18, 1858, p. 29, fig. 8, *left hand woodcut*), the primordial skull of *Gasterosteus* is given at a stage corresponding to this; and in the 'Elements' another figure of this stage (p. 185, fig. 72, *A*) is given, with the remark that "this is the earliest condition of the cartilaginous cranium of the osseous fish that has yet been observed;" "but," the author goes on to say, "it can hardly be doubted that the hyo-mandibular and palato-quadrate cartilages have already deviated considerably from their primitive condition; and it would be a matter of great interest to ascertain whether these cartilages are primitively continuous, or whether, on the other hand, the hyo-mandibular altogether belongs to the second visceral arch, while the hinder crus of the palato-quadrate belongs to the first, but has become detached from its primitive connexion with the *basis cranii*." That passage was written in 1863; since then neither repeated discussions nor the light from other types that have been more or less fully worked out have given us any satisfactory solution of the question. I am gratified by knowing that the author is satisfied with the solution offered him; and I have here given *four* stages earlier than the one supplied by the young *Stickleback*. How admirably apt and simple are the metamorphic changes by which a few hooked and twisted rods of simple cartilage grow and change, splitting or coalescing, contracting or dilating, and thus by a few orderly morphological processes develop the most highly specialized face-apparatus to be seen in the whole circle of the Vertebrata! We have just seen how the circle of the eyes is finished, above, by the superorbital band, an *eave-like* band which connects the frontal *tent* with the ear-organ: we now come to the condition of the *sill* of the huge eye-space (Plate IV. fig. 1), a structure which has given the morphological student no little trouble. This second "præoral arch" does not continue distinct as in the Bird, but coalesces with the fore edge of its successor, the first "postoral." Articulating by a short "ligamentum teres," which leaves no joint-cavity, with the ectoethmoidal facet, this semilunar rod then thins out (figs. 1, 2, 3, see also Plate III. figs. 7, 8, 9, *pa.*), and running upwards applies its apical part to the "orbitar process" of the quadrate. In doing this it loses somewhat of its crescentic form, becoming *in-hooked* at its apex; thus it acquires, at last, the form proper to the species of arch to which it belongs*. The metapterygoid region (*mt.pg.*), not separated yet by ossification, has already acquired the form seen in the adult, being now flat and emarginate above. The rest of the pier of the first "postoral" is flat, until we come to the elegant quadrate condyle (*q.*), the angle of the "palato-quadrate arch." The hinder outline of the pier is so convex that the whole arch still retains the primordial curve, broken in upon by the oblique fissure which formed the joint-cavity. The "articulo-Meckelian rod" (mandible, *ar.*, *mk.*) is thick and produced into an angle behind the selliform hollow for the quadrate; it then continues thick and terete to its rounded end. The whole of the first postoral pier is let down so as to be below the expanded head of its successor (fig. 1), which now carries it. Thus simple is the morphological process by which the curious protrusible mouth of a fish is constructed!

---

* If I have been able to get a lighted torch here it is not for the Fish only, as such, but *for use*, that the Bird, the Turtle, and many others may be understood. In the Bird the "orbitar process" is huge and gets outside and in front of the pterygoid, which, in articulating with the body of the quadrate, never fails to show an *apical process*; this epipterygoid hook is largest in the Grosbeak and in the Finches, its companions. In the "Testudinata" the pointed "orbitar process" merely touches the apex of the "epipterygoid columella;" whilst in Lacertians the process is aborted, and these arches are far apart.

The bony plates and the exact form, in section, of the mouth-margining cartilages are shown in the sectional views.

In the foremost of these (Plate III. fig. 7, *pa.*) the thick articular portion is shown to have at its infero-external face a delicate ectosteal lamina, the rudiment of the bony palatine. In the next (Plate III. fig. 8, *pa.*) the rod is flatter, and this is *behind* the bony plate. In the third (Plate III. fig. 9, *pa.*, *ms.pg.*) we have a perfect section of the mouth, and the palatine bar, much flattened, has a second bony lamina on its inner side, the "mesopterygoid."

The former, the palatine bony plate, has precisely the same relation in the young and old Sturgeon, and in old specimens the mesopterygoid is also well seen*. In the same section is seen the maxillary (*mx.*) and the Meckelian rod (*mk.*), perfectly round; on one side both the dentary and articulare (*ar.*) are seen, on the other only the dentary.

In the fourth section (Plate IV. fig. 7), which may be profitably compared to *two* similar views of the Tadpole's skull ("Frog's Skull," Plate vi. figs. 3 & 4), the coalesced "palato-quadrate" is cut through, the quadrate hinge being seen (*q.*) and the ascending pterygo-palatine bar (*p.pg.*). Below the quadrate is the articular region with its osselet (*ar.*), and beneath the section of the tongue and mouth-floor the crown of the inverted second "postoral" is cut through, showing the "basi- "hypo- and "cerato-hyals," in section and in relation. The great distance of the metapterygoid apex of the first "postoral" from the upturned postfrontal angle of the ear-sac is shown in the sixth section (Plate III. fig. 10, *mt.pg*); this part is *bent outwards*, the pier being in-bent where the two regions join: this is a correlate of the assumption of a new swinging-point, for the metapterygoid bends outwards to overlap the hyo-mandibular. Below the quadrate (*q.*) is the angular process of the articulare (*ar.*); below the back of the tongue (*t.*) is seen the fore end of the first basibranchial (*b.br.*), and on each side we see the "cerato-hyals" (*c.h.*) obliquely cut through.

Each hyoid ramus is now composed of four cartilages (Plate IV. fig. 1), which are ossified somewhat later than the arches in front; I did not find any traces of osseous deposit, even in transverse sections, highly magnified: the cartilages will now be described, and their osseous centres when I come to the seventh stage. To understand the state of things, reference must be made to the first splitting up of the "second postoral," and to the changes seen in the third and fourth stages; these have been just described.

---

* See my paper in Micr. Journ., June 1873, plate 20. fig. 5, *pa.*, *ms.pg.*

But the hyo-mandibular (*h.m.*) showing yet no division by two osseous centres, and lying *behind* and not *within* the quadrate, is quite *Polypterine* in character. Reference to my second stage (Plate II. fig. 3, *h.m.*, *c.h.*), and to Dr. Traquair's figures of *Polypterus* (fig. 6, *H.M.*, *H.M′.*), will give us an explanation of a peculiarity to be seen in that "Ganoid"—namely, that the top of the newly separated "cerato-hyal" (*c.h.*) of the embryo Salmon, which is connected with the lower end by a constricted portion, has its counterpart completely segmented off in *Polypterus*; and this it is which forms the accessory *hyo-mandibular* of Traquair (*op. cit.* p. 176); it is an "upper cerato-hyal." The term "post-hyomandibular" must not be used for this, but for the hinder condyle of the true "hyo-mandibular," a part which becomes so strangely modified in relation to the organ of hearing in the Frog ("Frog's Skull," Plate vii. fig. 13, pp. 170, 171). The head of the "hyo-mandibular" of the Salmon at this stage is slightly divided into two parts; but although many "Teleostei" have two condyles to this bone, in the Salmon the joint-cavity continues single. The "opercular knob" is at this stage a mere obtuse projection; the cartilage narrows gently towards it, and then suddenly; and here it curls forwards, getting a little within the metapterygoid flap; then, applying itself to the hind edge of the quadrate, it is really wedged between the quadrate and the angular process of the "articular" region. At the convexity of its bend, behind, we find a cupped space rather on the inside; it is for the stylo-hyal (*st.h.*), and a joint-cavity here makes this a small ball-and-socket joint. Below this joint the cartilage belongs to the "symplectic" region; it becomes the *nail* which is driven in a slanting manner into the inner face of the quadrate.

The "stylo-hyal"* (*st.h.*) does not appear until the emergence of the head from the egg (Fourth Stage, Plate III. figs. 1 & 6); it is evidently developed in the *hooked apex* of the posterior half of the primary hyoid bar in the fourth, and in the adult stage it is too short to show much of the curve, but *now* it is very evident. The apex of the anterior half develops the opercular process (see Plate II. figs. 3 & 6, Plate III. fig. 6, and Plate IV. fig. 1, *op.c.*). It is also to be noted that the *anterior half* of the bar forms the "hypohyal" below, which it loses, giving it up to the next half; whilst the posterior half keeps its own *apical* segment, the "stylo-hyal," and gains a new *distal* segment, the "hypohyal." These changes of *number*, *form*, and *place* are to me very wonderful; yet I must give my account of them in patient detail, not the less that my wit will not reach to their meaning. The elements of this half-arch are tied to each other by fibrous bands; I can find no joint-cavity between them. The stylo-hyal, true to its original character as an inturned hook, is articulated *inside* the apex of the great outflattened cerato-hyal; this piece (*c.h.*) only gets to be *two* by ossification, the upper third having the epihyal as a centre; but the "synchondrosis" is not severed through.

This piece is very flat above, with rounded margins; but it contracts and thickens below, and then forms a swollen head, which fits into a corresponding depression in the distal piece, the hypohyal (*h.h.*); this latter part is very solid and is grooved below

---

* These terms are purely *ichthyic*, and are not to be confounded with like terms used for the higher Vertebrata; we are not quite prepared yet for an harmonious terminology.

(Plate IV. fig. 7). Upon the two "hypohyals" the lingual element or basihyal (*g.h.*) rests in its hinder part; its fore part projects into the substance of the tongue.

The branchial arches (Plate IV. fig. 1, *br.* 1–5) are still unossified, but their basal elements are being fused together; the relation of the foremost piece to the floor of the mouth is shown in section (Plate III. fig. 10, *b.br.* 1), and the second pharyngo-branchial in its relation to the basis cranii is shown in another section (Plate V. fig. 5, *p.br.* 2): in this section part of the first cerato-branchial region is cut through (*c.br.* 1), and here also is shown the articulation of the "hyo-mandibular" beneath the ampulla of the "horizontal canal" (*h.m.*, *h.s.c.*).

Sixth Stage.—Young Salmon of the sixth week after hatching.

In Salmon of this stage there has been an increase in length less than might be supposed from a month's growth; they are three or four lines longer than in the fifth stage (about an inch and a sixth), but the yelk-sac has been entirely taken into the abdomen, and the tissues have become very much more perfect and solid. Ossification has begun in the parosteal tracts generally, and in most of the ectosteal, but we shall not find the bony plates of the sphenoidal region for some weeks to come; and most of the ectosteal plates will be best described in Salmon of the first summer. Yet there are changes of great importance that have already taken place in the cartilaginous skull, which is now beginning to pass from the *Polypterine* into the *Salmonine* morphological type. The vertical section (Plate V. fig. 2) is shown with the brain removed, and this must serve for comparison with both the inner and outer views of the fifth stage (Plate IV. figs. 1 & 4). The middle ethmoidal region is now much more developed and is very solid, the nasal sacs lying, as in the Sturgeon, in little recesses or crypts on either side. The trabecular cornua are only separate at their ends by a very small emargination; these, and the septum common to both the nasal and anterior orbital region, are formed of continuous cartilage. This section, which is a little more than half, being made to the left of the exact mid line, shows what is most instructive, namely a *double origin* for the interorbital cartilage. The "mesoethmoid," besides being continuous with the prosencephalic cartilaginous roof, also sends a sharp, wedge-like lamina *backwards* into the presphenoidal region; and besides this the coalesced tilted trabeculæ have sent *upwards* another lamina, which runs from the ethmoidal to the basisphenoidal region, some distance below the presphenoid. Here, evidently, we are beginning to get a clue to the remarkable characters of the Bird's skull, in which the differentiation of morphological regions often takes place some days after the formation of continuous hyaline cartilage over several truly distinct parts. In the Bird (*chick*) the distinctness of the trabeculæ from the "investing mass" is best shown during the second week of incubation, and the morphology of the interorbital plate is best studied at the beginning of the third. I have shown this breaking up of large parts of the cartilage into more or less distinct morphological elements in the "shoulder-girdle" in my memoir on that part of the Vertebrate skeleton; and it must not be supposed incredible that morphological differentiation of the skull may often not be exhibited until the cartilage has in many cases been converted into bone. The skull of a Shark and that of a young Rodent (after the osseous centres are all formed) may be profitably compared together; for it would seem that in the Mammalia alone does the skull perfect its segments—segments altogether so unlike those which form the rest of the axis, and which are most truly primordial*.

The membranous interorbital space in the young Salmon is the equivalent of the "fenestra" in the Bird, formed by retreat of the ethmo-presphenoidal cartilage from the trabecular crest. In *Pelecanus onocrotalus* both the præoral arches behave in a similar manner; both coalesce in front of the elbowed part, and both of these double bars send upwards an azygous keel. I shall have to return to this comparison in describing the next stage. The trabecular carina only reaches to the converged part of the trabecula; the ethmo-presphenoidal wedge only takes up the front third of the prosencephalic (anterior sphenoidal) region (Plate V. fig. 2). The cranial roof is thicker, and extends further over the middle cerebral lobe than in the last stage, and the band which unites the roof to the ear-capsule is broader and shorter. The alisphenoidal region is beginning to be walled-in by a growth of cartilage *downwards* from the *band*, and forwards and inwards from the ear-sac; for the rest, this region is membranous, as in the Lacertilia. The Lizards have an orbito-sphenoid *mapped out* by an outline of partly ossified cartilage, and the band at the top of this region answers, as far as it goes, to the *very edge* of the roof-cartilage of the young Salmon; but there is no band running to the periotic region, and the only probable rudiment of an alisphenoid in the skulls in my collection is a small *epiphysis* at the antero-superior angle of the prootic in a Mexican Lizard (*Læmanctus longipes*). In the young Salmon the anterior sphenoidal region, although well roofed-in, has no cartilage in its side walls, as in the *carinate* Birds and "Struthionidæ," with the exception of *Struthio*. The "fontanelle" is still very large (*fo.*), yet the superoccipital cartilage (*s.o.*) reaches to the junction of the anterior and posterior semicircular canals (*a.s.c.*, *p.s.c.*). How large these and the other parts of the labyrinth are the figure shows, and also how the periotic cartilage fails to enclose the ampullæ and most of the arch of the anterior and posterior canals, as well as the "utriculus" (*ut.*) and "sacculus" (*sc.*). The strong sheath of the notochord is now beginning to be ossified, and thus to lay the foundation of the "basioccipital," *but of it alone*; the posterior part of the investing mass" (*iv.*) forms additional substance for the completion of this *quasi centrum*. The roof-bones are not shown in this figure, except the "superethmoidal lamina;" the premaxillary is also cut through; and the long "parasphenoid" has now the "vomer" beneath its fore end, and to it are attached a number of teeth.

A section (Plate V. fig. 3) immediately in front of the projecting "ectoethmoidal wings" (prefrontal lobes) shows at this stage a very complete coalescence of the upgrowths of the trabecular horns, and the width and thickness of the subnasal lamina just in front of the facet for the palatine; the skull now at this part is very *Acipenserine*. In this section the nasal sacs are severed at their opening, the lateral parts of the premaxillaries are cut through, the fore part of the parasphenoid, and the "prepalatine" bar with its ectosteal plate. Another section (Plate V. fig. 4), made near the fore part of the orbits and a little obliquely, shows on one side part of the antorbital (ectoethmoidal) plate, and on the other the *roof-cartilage*. This is a most instructive section, and should be compared with a similar section of the Fowl's skull made at the beginning of the third week of incubation ("Fowl's Skull," Plate LXXXIII. fig. 11, *p.s.*, *i.o.s.*, *b.s.*): for the crest growing down from the roof is the "mesoethmoid" passing into the presphenoid; the roof itself ends in the Bird in a spike above the olfactory groove, and in the young Salmon in the free, retral, median lobe. Below, the tilted coalesced trabeculæ send up their crest, in which the lower part of the "mesoethmoid" passes *below* the presphenoid into the basisphenoidal region; this will be better understood in the next stage. Here we see the raised middle of the "parasphenoid" applying itself to the trabecular groove and the tilted and broad "mesopterygoid" region of the subocular arch (*pa.s.*, *pa.*). In another section (Plate V. fig. 1), made through the fore part of the auditory capsule, we see the ampulla and part of the arch of the anterior canal (*a.s.c.*) overlying the hyo-mandibular (the fore part of which is cut through), and forming the tegmen tympani. Here the skull is widest, for it covers in the posterior part of the middle lobe of the brain, where it overlaps the posterior region; here was seen, inside the ampulla of the anterior canal, the Gasserian ganglion (5). The posterior branch of this fifth nerve is seen passing through its own foramen in the "prootic" cartilage; and the fore part of the investing mass, confluent with the ear-cartilage, is undergirded by the "basitemporal wings" of the parasphenoid, over which lie the orbital muscles (*o.m.*). Here also is well seen the manner in which the periotic cartilage is folded over the semicircular canal, but fails to wall it in; the sharp edge above is that which runs into the boundary-band that comes from the sides of the cartilaginous roof.

---

* In all generalizations of this sort the *Amphioxus* is left out of the question; when we obtain links that will in any way bind it to the Myxinoids, then we may begin to reason from a higher stand-point (see "Frog's Skull," p. 202).

Seventh Stage.—Young Salmon of the first summer, $1\frac{1}{2}$ to $2\frac{1}{4}$ inches in length.

We have now come to a stage in which the Ganoid characters are being rapidly effaced, whilst that which is "Teleostean" has become apparent. In this arbitrary but not non-natural *seventh age* of the Salmon we are able to detect not only the *intermediate* laminæ of bone in which the cartilaginous skull is arrayed, and by which, as in proven armour, its possessor takes a high ichthyic rank, but we have now rudiments, at least, of all the *deep* laminæ that graft themselves upon the cartilage within. The cartilaginous skull itself has become much more massive, and it is no hard task now to harmonize the skull of the young with that of the adult. Holding in mind the condition of the last stage (Plate V. figs. 1, 2, 3, 4), we see that the cartilaginous roof is increasing in thickness, and extending backward over the middle cerebral region, whilst the sharp edges of cartilage (behind from the occipital ring, and postero-laterally from the cartilaginous ear-sacs) are growing more over the third vesicle and cerebellum. The roof-cartilage is thicker (fig. 10) and has developed an inturned selvedge, which encroaches upon the membranous orbito-sphenoidal region, whilst the "mesoethmoidal" wedge has grown further backwards along the presphenoidal line. A thin spicule of bone has been formed over the "ectoethmoidal wing" (figs. 7 & 9, *l.e.*), and this does not behave like the "supraethmoidal" plate (fig. 6, *n.**), but grafts itself upon the cartilage and becomes the so-called "prefrontal" bone. In the prosencephalic region I have not figured the permanently distinct frontals above; but laterally there are now a pair of new bones to be illustrated (figs. 6, 7, 9, 10, *o.s.*). These laminæ are like the valves of bivalved "Entomostraca," and occupy already nearly the whole of the orbito-sphenoidal space. These bones curiously illustrate, and are illustrated by, their counterparts in two very diverse types of Vertebrata: they have precisely the same character, as bones, as those developed over the "orbito-sphenoidal" cartilage of the Sturgeon; there, however, they continue as distinct "investing bones," even to old age (see adult Sturgeon's skull, with soft parts modelled, in Mus. Coll. Surg.). In the Fowl, at the time of hatching, the orbito-sphenoidal region ("Fowl's Skull," Plate LXXXIV. figs. 7 & 8, *p.s.*) is entirely membranous; it has no alæ growing from the presphenoid (ibid. Plate LXXXIII. fig. 11, *o.s.*, *p.s.*); but in a few weeks *two* membrane-bones appear on each side, and these soon graft themselves upon the presphenoid (see also Plate LXXXVI. figs. 11 & 14, and Plate LXXXVII. figs. 1 & 2, *o.s.*, *p.s.*). The *single* bone in the young Salmon grafts itself also upon the presphenoid exactly in the same way (Plate V. figs. 6, 7, 9, 10, *o.s.*, *p.s.*); and not only so, but the upper edge of each plate splits and embraces the descending roof-plate (fig. 10). That this is not done in the case of the Bird also, depends upon the fact that the "culmen cranii" growing backwards from the "ethmoid" is arrested midway (ibid. Plate LXXXIII. figs. 2, 4, 5, Plate LXXXIV. fig. 7, Plate LXXXV. fig. 1, and Plate LXXXVI. figs. 11 & 14, *o.s.*, *eth.*). There is no difficulty now in understanding the meaning of the great interorbital bone of the adult Salmon (Plate VII. figs. 3, 4, 10, *o.s.*), nor in seeing why it is arrested in its growth downwards; in like manner the *distinct* presphenoid of the Fowl (*op. cit.* Plate LXXXVII. fig. 1, *p.s.*) reaches no further downwards than to the top of the *trabecular keel*, in which the mesoethmoidal and basisphenoidal ossifications meet. Now we know that the *primordial* "notch" between the upper and lower retral median cartilages that grow from the ethmoid in the Salmon answers to the *secondary* "fenestra" of the Bird, it becomes a question of intense interest as to what the lower bar is, as well as how it comports itself. *Here*, in the Salmon, there is no median ethmoidal ossification; *there*, in the Bird, the basisphenoid borrows its ossifying centre at first from the parasphenoid, a bone permanently distinct in the Fish, but the median ethmoid becomes an immense bone (*op. cit.* Plate LXXXVII. fig. 1, *eth.*), all arising from a single centre†.

But the *prepituitary* part of the basisphenoid is formed, as to cartilage, in the same way—namely, by the extension backwards *below the optic nerves* of the "trabecular crest." In the Bird this crest ("Fowl's Skull," Plate LXXXIII. fig. 14, *b.s.*) expands in front of the pituitary body into the "anterior clinoid wall" (Plate LXXXIII. fig. 2, *a.cl.*). In the Fish the trabecular crest runs into the pituitary space, *between* the out-bowed part of the trabeculæ (Plate V. figs. 6 & 7). Thus the foundation of the clinoid wall is laid in cartilage, but the wall itself is finished in another way. The membranous septum *behind* the optic nerves becomes partially ossified; this osselet is a Y-shaped little *prop*, the arms of which seize the lower edge of the alisphenoids, and the leg of which is implanted upon the rounded end of the trabecular crest (Plate V. figs. 6 & 7, Plate VII. figs. 3 & 4, and Plate VIII. figs. 2, 3, 4, *b.s.*). At first (Plate V. figs. 6 & 7) the foot of the bone does not reach the cartilage, but they grow towards each other afterwards. This bone is a *prepituitary* "basisphenoid;" it is a deep lamina or "ectostosis," and it becomes one with the primordial skull both above and below. Immediately behind this bone the pituitary body (Plate V. figs. 6 & 7, *py.*) descends to reach the "parasphenoid;" there is no other *seat* to the "sella turcica;" and on each side the internal carotid artery (*i.c.*) enters.

---

* The "mesonasal" is lettered *n* by mistake in these figures (2 and 6); it is marked *eth.* in the rest.

† Not in the "Ratitæ," however (see "Ostrich's Skull," Plates VIII.–XIV.); here the *roof* is separately ossified.

Before leaving the fore part of the skull I may refer to the extraordinary expansion which the trabeculæ have already undergone. At first (Plate I. figs. 1 & 2, *tr.*) they were filiform thickenings; they soon (fig. 5, *tr.*) spread into a bifoliate form; the "bifoil" has already become differentiated into a "meso-" and an "ectoethmoidal" region. Now see what has taken place! Between the eyes we have the grooved interorbital base (Plate V. fig. 9), then the wide floor of the "ectoethmoid" with the "palatine *facets*," then the floor of the nasal sacs, and, lastly, the emarginate trabecular plate formed by the trabecular horns (ethmo-vomerine cartilage of HUXLEY). Above, the lateral parts have grown into the sloping prefrontal wings, which meet in the *roof-cartilage*, whilst along the mid line there grow backwards those two most important crests, the "ethmo-presphenoidal" and the "trabecular."

We never see a *cranium* pure and simple; for the outgoings and incomings of nervous force there are required appropriate organs that either nestle under the eaves of the skull or are projected into its walls. All the space from the great fifth nerve to the *compound* eighth is occupied by the antechambers, chambers, and galleries of the ear-organ; here no fence but membrane and a gelatinous stroma is interposed between the brain and the labyrinth. But the skull on the outside becomes exceedingly strong by this impaction of the organs of hearing; the rudiments of the thick bony blocks that exist in this part of the adult are now to be seen as their "ectostoses." But the auditory region is fringed on its anterior margin by a slight cartilaginous growth, the thick upper selvedge of which is formed by the "superorbital band;" this fringe is undergoing ossification, and is the "alisphenoid;" as I have just mentioned, it is underpropped by the Y-shaped bone. This is a very unfinished skull as far as the sphenoids are concerned, and has little in common with what we are all familiar with in the human skull and in that of the Mammalia generally. In the Mammalian skull all that part of the anterior sphenoid occupied by the "culmen cranii" is membranous, and the membranous orbito-sphenoids of the Salmon are represented by cartilage in the Mammal. Again, the alisphenoids of the young Salmon are scarcely more free from the ear-cartilage than the laminar growth of the prootic region in an average Mammal (see in the Beaver, HUXLEY'S 'Elem.' p. 245, fig. 97, *as.*, *pro.*); but where the alisphenoid of the Mammal thins out above, there in the Fish it has a thick selvedge, connecting it both with the ethmoidal roof and the periotic capsule. The basisphenoidal region is also in a most rudimentary and, as it were, fragmentary condition; for there is a feeble prepituitary portion, an open *sellar* space, and the cartilage (*basilar*) which should form the posterior clinoid wall, the postpituitary region, and the spheno-occipital synchondrosis,—all this is trespassed upon by the "prootic bones," which borrow it to form their curious basicranial bridge.

Relatively to the rest of the skull the auditory capsules are very large; their centres of ossification are curiously placed—one on the anterior margin behind and above the main part of the fifth nerve, and perforated by the posterior branch, and the other *four* forming a *right*-angular series along the most projecting part, covering the galleries of the labyrinth (Plate V. fig. 7). The first is the "prootic" (*pro.*); the second, which is over the ampulla of the anterior canal, is the "sphenotic" (*sp.o.*); the third, over the ampulla and arch of the horizontal canal, is the "pterotic" (*pt.o.*); the fourth, over the arch of the posterior canal, is the "epiotic" (*ep.*); and the fifth, which is over its ampulla, is the "opisthotic" (*op.*). Of these Professor HUXLEY is responsible, as to nomenclature, for *three*, the "tria ossicula" of KERKRINGIUS, who described them in the human skull (see HUXLEY'S 'Elem.' p. 153); the other *two* which I contend for are the "sphenotic" and "pterotic." At present these bones are in their infancy, the cartilage is whole beneath them; it still retains the impressure and form of the elegant and large elements of the labyrinth. The most exquisite part of this cartilaginous capsule is seen beneath the "tegmen tympani" and facet for the "hyo-mandibular;" this is the ovoidal pouch for the "sacculus," which lies between the foramen for the "portio dura" (7^a) and that for the compound eighth nerve (8). The antero-superior part of this "saccular recess" is occupied by an *oval fenestra*, the primordial deficiency already described (see Plate II. fig. 4); it does not, however, persist, but closes as in the third stage of the Frog, and does not reopen as in that air-breathing type (see "Frog's Skull," Plate IV. fig. 7, and Plate V. figs. 1 & 4, *au.*, *st.*). That out-bent part of the trabeculæ, the *apical* part which joins the "investing mass," is still present, but is a temporary structure; thus the three anterior facial arches all escape away from their primary relations to the base and sides of the cranium. The lowered position of the pterygo-palatine and mandibular arches is shown in the next figure (fig. 8; *the rest of the face detached from the skull*, fig. 7).

The "superoccipital" region is now invested by an ectosteal lamina, and the "foramen magnum" is bounded laterally by a pair of crescentic ossicles, the exoccipitals (Plate V. figs. 6 & 7, *so.*, *eo.*).

The ossified sheath of the notochord (*nc.*, *bo.*), the median, hollow, styloid rudiment of the "basioccipital," has not much affected the posterior half of the "basilar plate," as yet*.

One of the peculiar characters of the palato-pterygoid bar is its projection beyond the prefrontal attachment; it is a part well marked in the newly metamorphosed Frog ("Frog's Skull," Plate VII. fig. 11, *pr.pa.*). The Lamprey, evidently related to the prototype of the Frog, has it also in the same degree (MÜLLER, 'Myxinoids,' pl. 4. fig. 3, *under view*), although in that low Fish the half-suppressed bar corresponds on the whole with my fifth stage, or Tadpoles that have begun to acquire limbs.

The long suppression and the secondary character of this bar made me waver for a long while as to the true morphological character of this arcade; but I have no doubts left now, and shall speak of it unhesitatingly as the "second præoral arch." The prepalatine spur is normal enough when it is regarded as the terminal part of a facial rod; and the points of attachment of this bar are easily understood to be consistent with the *habit* of these arches generally, as they are always catching hold of each other to form a basketwork. Posteriorly this bar does not connect itself with the trabeculæ, as in the Lizard and the Bird, but its apex is completely fused with the fore edge of the pier of the mandible, with the well-known "orbitar process." *Under* the fore part the palatine ectostosis (Plate V. fig. 8, *pa.*) bearing teeth has begun to invest the cartilage; *below* the hinder part, and more within than without, is the "pterygoid" plate (*pg.*); and *over* the middle part is the "mesopterygoid," an ovoidal shell of thin bone with its hollow face looking inwards (*m.pg.*)†.

At the apex of the lowered mandibular pier the ear-shaped "metapterygoid" (*mt.pg.*) has worked into the fore half of the cartilage; and below the "quadratum" (*q.*), which began on the *outside*, as in the Frog, Newt, and Lepidosiren, has grown to a very elegant flabelliform bone with a *periosteal* posterior wing that is grooved on its inner face, and into which the symplectic is inserted obliquely, like a badly driven nail. The unossified quadrate angle forms an elegant condyle, which fits into a deep fossa in the "articular" end of MECKEL'S cartilage; this, with its largely projected angle, is very much like the human "ulna;" the joint is a simple hinge. In front of the angular and articular region MECKEL'S cartilage retains its old cylindrical form, and has its rounded end incurved as at first. Much of the lower edge is occupied with a lanceolate "articulare" full of spongy hollows, the primary lamina subdividing again and again (see Fifth Stage, Plate III. fig. 9, *ar.*).

The "hyo-mandibular" (*h.m.*), although made now the common suspensorium of these massive bars, is as yet not over large, as we see it in the adult; its long process has now the proper "symplectic" bony sheath (*sy.*), in addition to the other ectostosis on the main part. The opercular knob (*op.c.*) is large and well defined. The synchondrosis below the two bones is hollowed inside and behind for the head of the short "stylo-hyal" ray (*st.h.*), which is now enclosed in its own bony sheath. The lower end of the "stylohyal" is attached by a fibrous cord to the next cartilaginous bar, which has two ectosteal sheaths (the "epihyal" and "cerato-hyal" proper, *ep.h.*, *c.h.*). The rounded cerato-hyal end fits into the cupped surface of the thick bulbous distal "hypohyal" (*h.h.*); there is no joint cavity between them. There is a cavity, however, between the hypohyal and the azygous piece, the keystone of the arch; this is the *glossal bone*, or true "basihyal" (*g.h.*); it has now a dentigerous bony lamina, its proper ectosteal plate, whilst the hypohyal, short as it is, has two centres of ossification.

---

* It is easy to see that if the vertebrate animal had been, in each or any case, *anencephalous*, then the materials were at hand, in the notochord, its sheath, and the basilar plate, for several vertebræ, which would have elegantly diminished in size from behind forwards; the tantalizing *Amphioxus* merely throws a "will-o'-the-wisp" light on this dark margin of vertebrate morphology.

† In determining these bones in other types, it should be recollected that the "palatine" plate is *under* and *outside*, the "mesopterygoid" *over*, and the pterygoid *under* and *within*; this may help the palæontologist with his "Ganoids" and other extinct types.

As this present paper is merely the first of a series which I hope to offer to the Royal Society on the Fish's Skull, I shall refrain from making any SUMMARY. The Teleostean must be studied in the light of the other ichthyic types; there is the more need for this, as it is, indeed, the most specialized of all. When the "Marsypobranchs," "Elasmobranchs," "Dipnoi," and "Ganoids" are thoroughly worked out it will be easy to summarize the facts obtained. With regard to the Salmon itself, the reader is referred to a very important work on its structure by Dr. CARL BRUCH, 'Vergleichende Osteologie des Rheinlachses (*Salmo salar*, L.) mit besonderer Berücksichtigung der Myologie, nebst einleitenden Bemerkungen über die skelettbildenden Gewebe der Wirbelthiere' (Mainz, 1861).

DESCRIPTION OF THE PLATES.

PLATE I.

First Stage.—Embryos from the egg with simple facial arches.

Fig. 1. Lower view of head, with facial arches shining through. ×20 diameters.
Fig. 2. Upper view of same specimen, with skin partly removed. ×20 diameters.
Fig. 3. Lower view of another head, partly dissected. ×20 diameters.
Fig. 4. Upper view of head, undissected. ×20 diameters.
Fig. 5. Another upper view, dissected. ×20 diameters.
Fig. 6. Side view of head within chorion. ×20 diameters.
Fig. 7. Another head, seen from below (dissected). ×20 diameters.
Fig. 8. Part of section of egg with contained embryo, cut longitudinally. ×20 diameters.
Fig. 9. Head of another embryo, obliquely shown. ×20 diameters.
Fig. 10. Transverse section, through the eyes, of an unusually symmetrical embryo. ×26 diameters.
Fig. 11. Another transverse section, further back. ×26 diameters.

PLATE II.

First Stage (continued).

Fig. 1. Section, through the eyes, of an unsymmetrical embryo. ×24 diameters.
Fig. 2. Another similar section, further back. ×24 diameters.

Second Stage.—Embryos with hyoid arch split up.

Fig. 3. Under view of head, somewhat depressed. ×24 diameters.
Fig. 4. Under view of same head, with postoral arches removed. ×24 diameters.
Fig. 5. Part of another skull. ×30 diameters.

Third Stage.—Mandibular arch segmented.

Fig. 6. Lower view of skull and face, with branchial arches removed. ×24 diameters.
Fig. 7. Same object, upper view. ×24 diameters.
Fig. 8. Branchial arches of same, separately shown, from below. ×24 diameters.

Fourth Stage.—Head emerging from the chorion, and hatched embryos.

Fig. 9. Front view of head. ×20 diameters.
Fig. 10. Section of the same, through the eyes. ×20 diameters.
Fig. 11. Upper view of head. ×10 diameters.

PLATE III.

Fourth Stage (continued).

Fig. 1. Side view of head, with face dissected. ×25 diameters.
Fig. 2. Lower view of same, dissected. ×25 diameters.
Fig. 3. Section of head of partly hatched embryo. ×20 diameters.
Fig. 4. Side view of head of hatched embryo. ×20 diameters.
Fig. 5. Section of the same. ×20 diameters.
Fig. 6. Primordial skull of same, from above. ×25 diameters.
Fig. 7. Section of ripe embryo-head through nasal sacs. ×25 diameters.
Fig. 8. Another section through prosencephalon. ×25 diameters.
Fig. 9. Another through the same, and also the eyeballs. ×25 diameters.
Fig. 10. Another section, behind the eyes. ×25 diameters.
Fig. 11. Another section, behind the left ear-sac. ×25 diameters.

PLATE IV.

Fifth Stage.—"Fry" the second week after hatching.

Fig. 1. Side view of primordial skull. ×24 diameters.
Fig. 2. Upper view of same. ×24 diameters.
Fig. 3. Lower view of same. ×24 diameters.
Fig. 4. Vertical section of the head. ×24 diameters.
Fig. 5. Part of same section. ×48 diameters.
Fig. 6. Another vertical section (part) a little to the right. ×24 diameters.
Fig. 7. Section through the eyes (*of fourth stage*). ×25 diameters.

PLATE V.

Sixth Stage.—Young Salmon of the sixth week after hatching.

Fig. 1. Transverse section through anterior part of auditory capsule. ×20 diameters.
Fig. 2. Section of head (vertical). ×16½ diameters.
Fig. 3. Transverse section through nasal sacs. ×20 diameters.
Fig. 4. A similar section through fore part of orbit. ×20 diameters.
Fig. 5. Section through ear-sac (*fifth stage*). ×20 diameters.

Seventh Stage.—Young Salmon of the first summer, 1½ *to* 2¼ *inches long.*

Fig. 6. Vertical section of head. ×15 diameters.
Fig. 7. Side view of skull. ×15 diameters.
Fig. 8. Facial bars of same. ×15 diameters.
Fig. 9. Lower view of face. ×20 diameters.
Fig. 10. Section of fore part of skull. ×15 diameters.

PLATE VI.

Eighth Stage.—Adult Salmon.

Fig. 1. Side view of skull and face. Nat. size.
Fig. 2. Same, with outer bones removed. Nat. size.
Fig. 3. First branchial arch. Nat. size.
Fig. 4. Second branchial arch (part). Nat. size.
Fig. 5. Lateral view of basibranchiostegal. Nat. size.

PLATE VII.

Eighth Stage (continued).

Fig. 1. Upper view of skull with bony plates on. Nat. size.
Fig. 2. The same, from below. Nat. size.

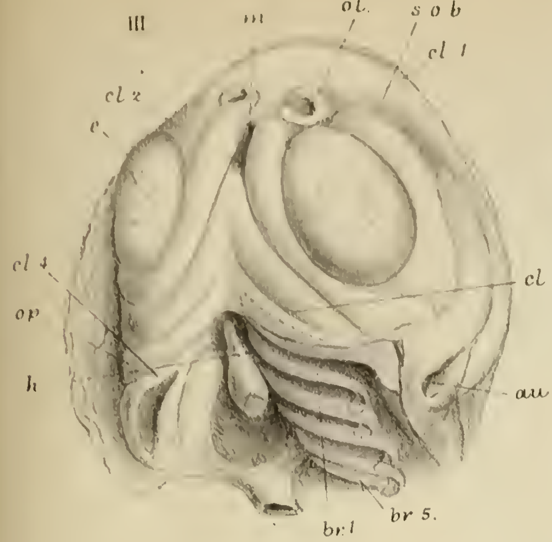
Fig. 3. Side view of skull, with bony plates removed. Nat. size.
Fig. 4. Vertical section of skull and bony plates. Nat. size.
Figs. 5–11. A series of transverse sections of skull, with bony plates on. Nat. size.

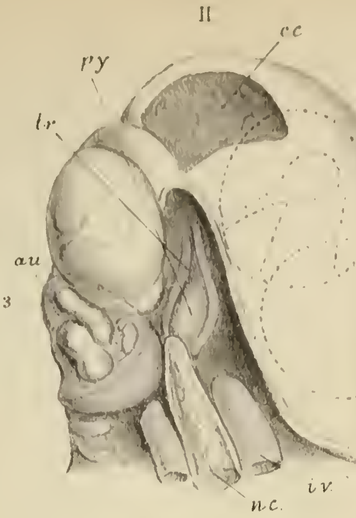
PLATE VIII.

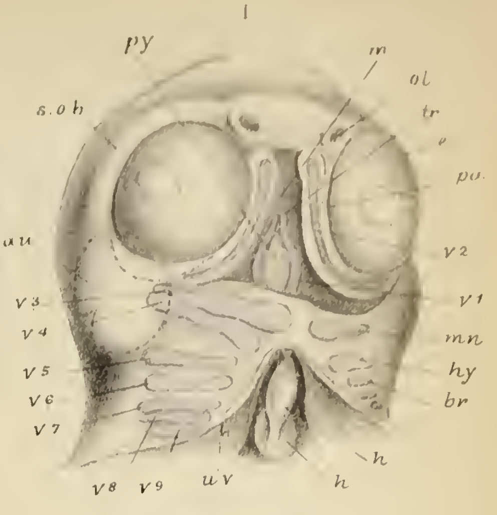
Eighth Stage (continued).

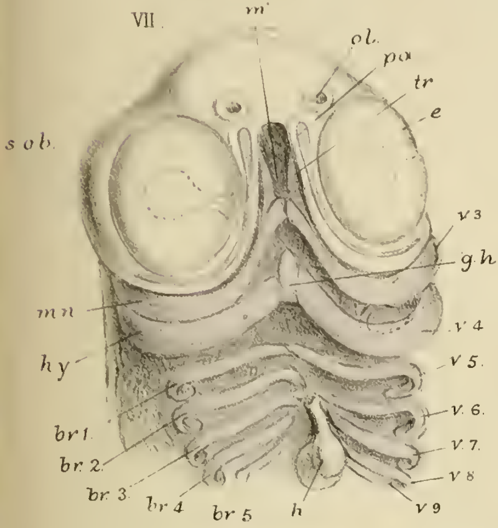
Fig. 1. Skull, from above, bony plates removed. Nat. size.
Fig. 2. The same, from below. Nat. size.
Fig. 3. Part of a vertical slice of the skull. Nat. size.
Figs. 4–7. The rest of the series of transverse sections. Nat. size.
Fig. 8. End view of skull. Nat. size.
Fig. 9. Inner view of facial arches. Nat. size.

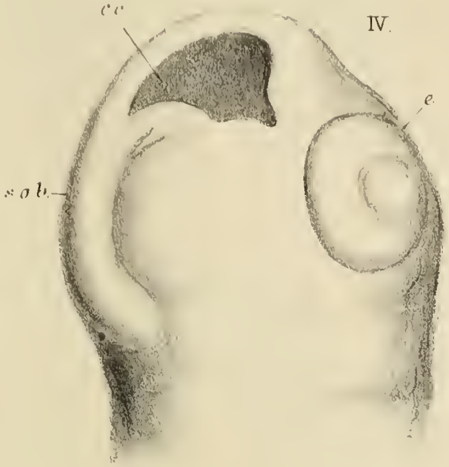
LIBRARY
OF THE
UNIVERSITY of ILLINOIS

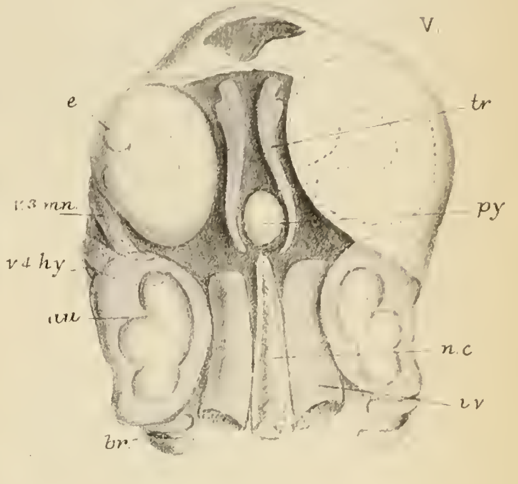


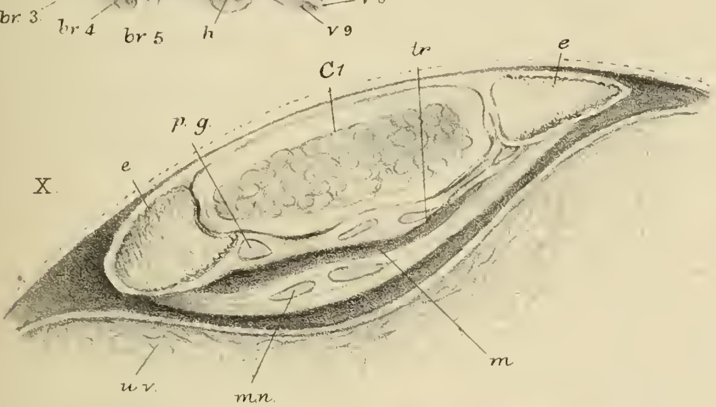


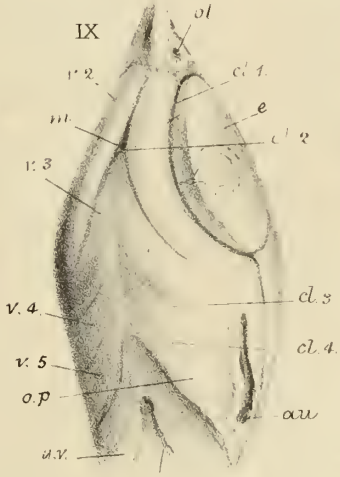


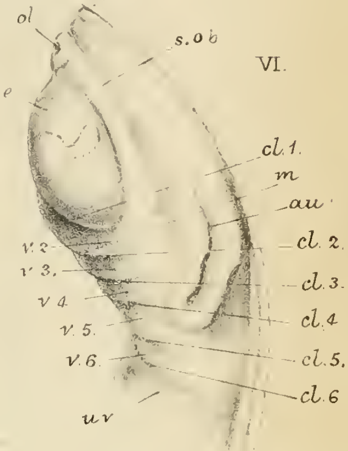


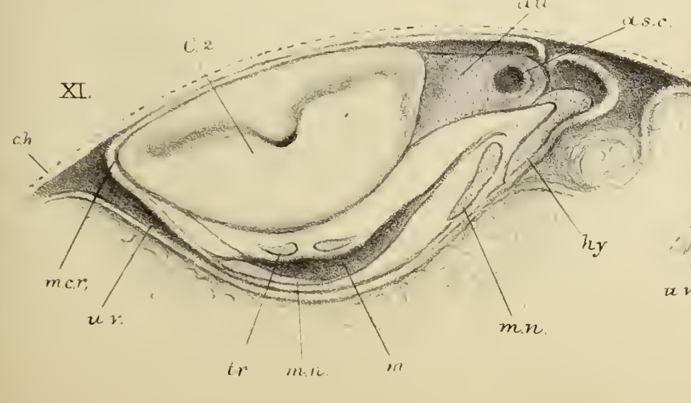


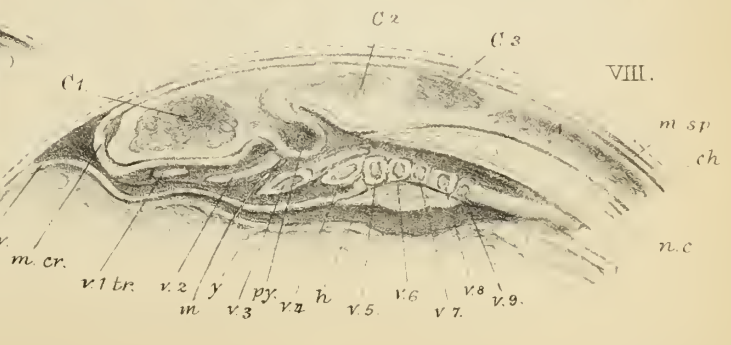










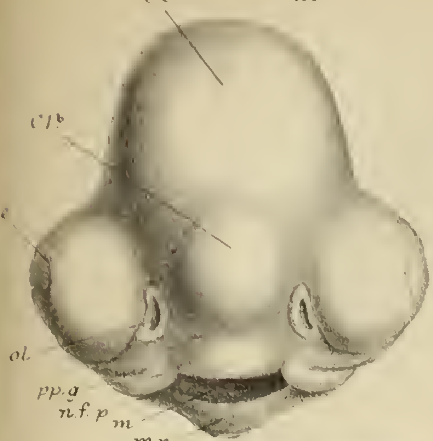


W.K.P. del ad nat. Geo. West lith.

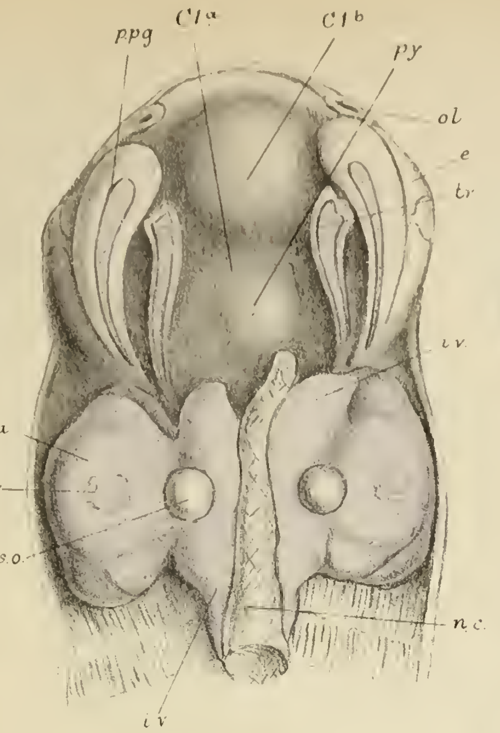
W. West & C° imp

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

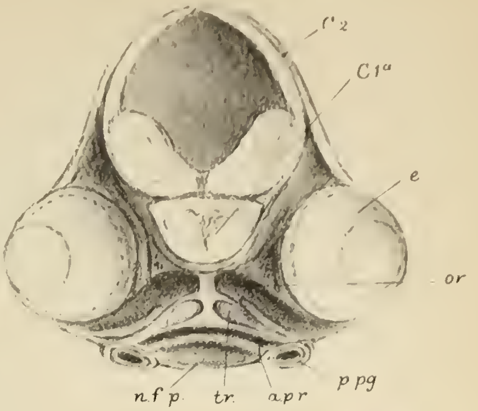
IX



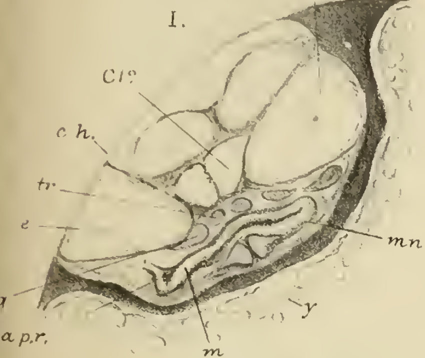
IV



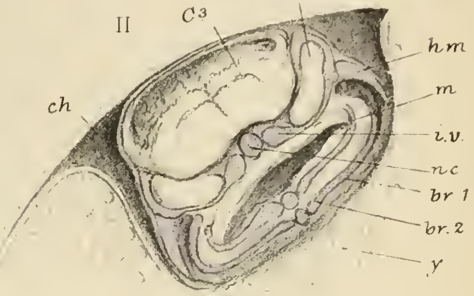
X



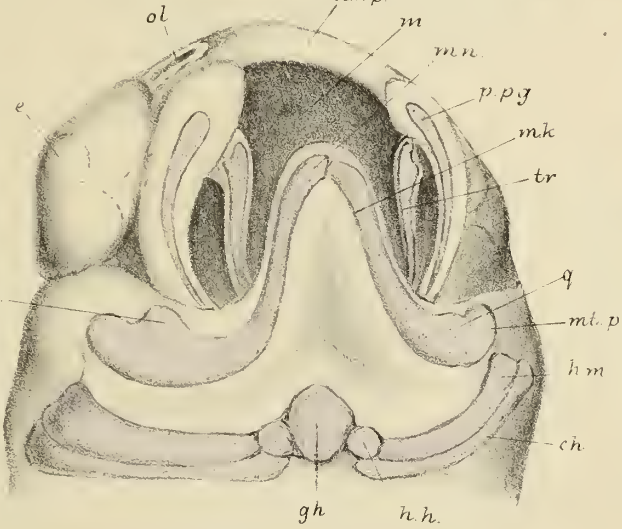
I.



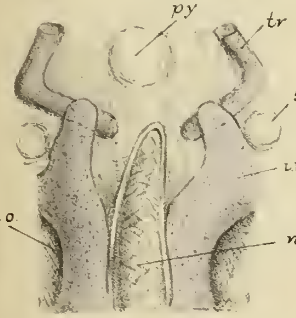
II



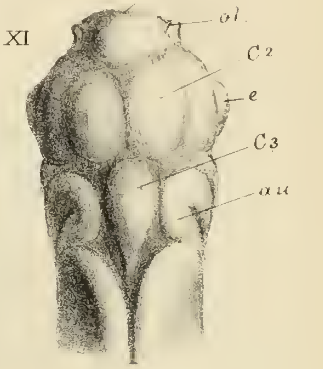
III



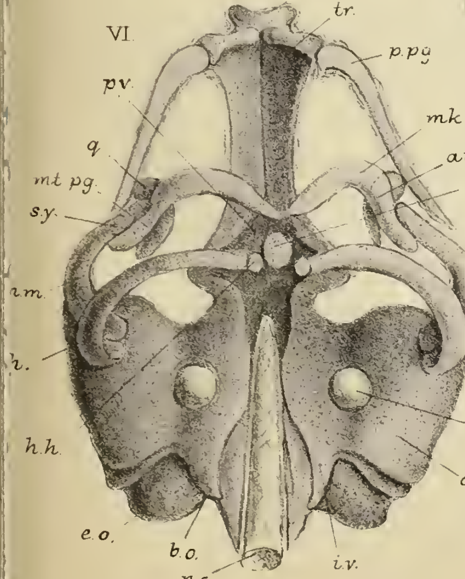
V.



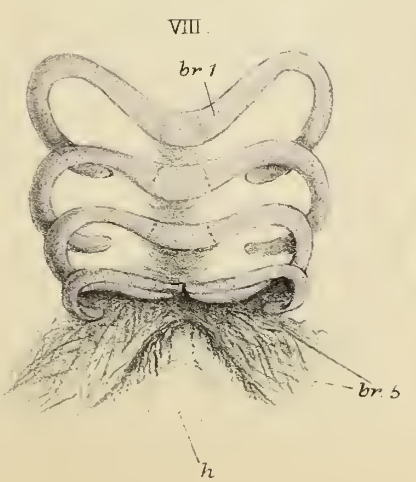
XI



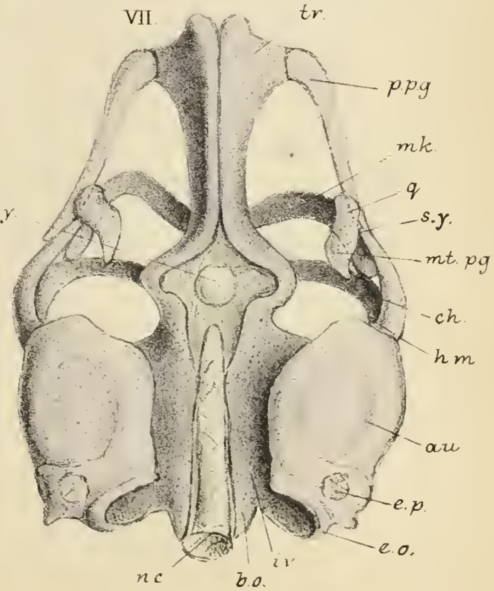
VI.



VIII.

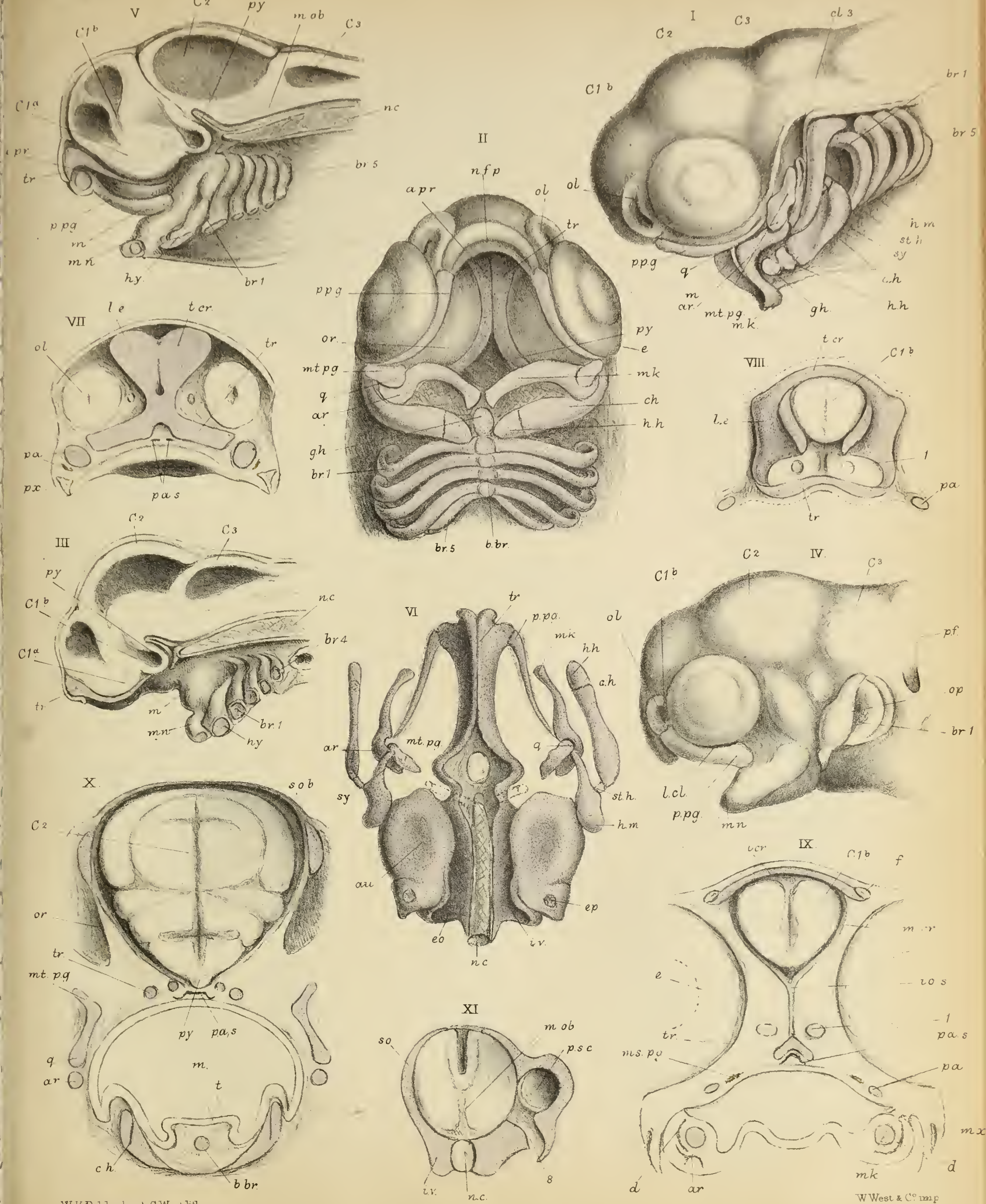


VII.



W K P. del ad nat, Geo West lith.
W. West & Co. imp

UNIVERSITY of ILLINOIS

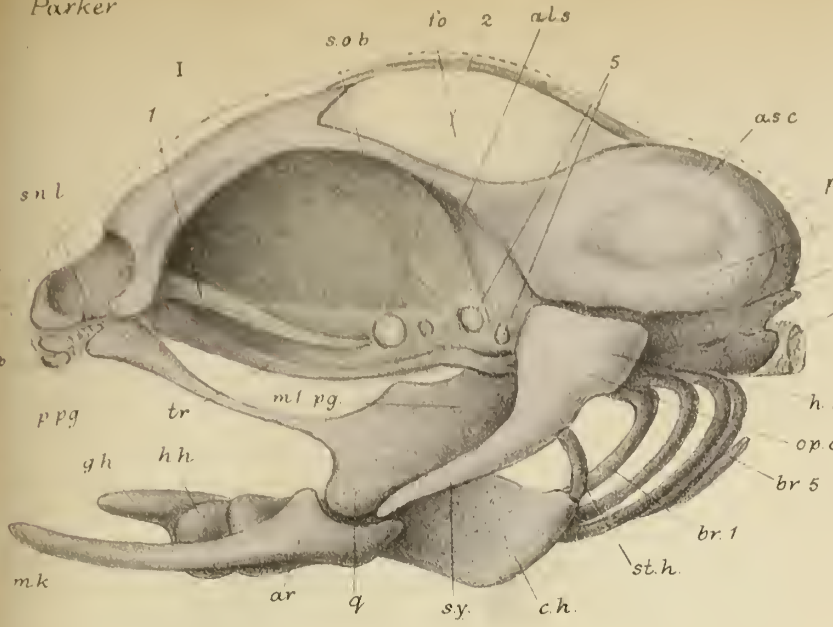


W.K.P. del. ad nat. G. West lith.

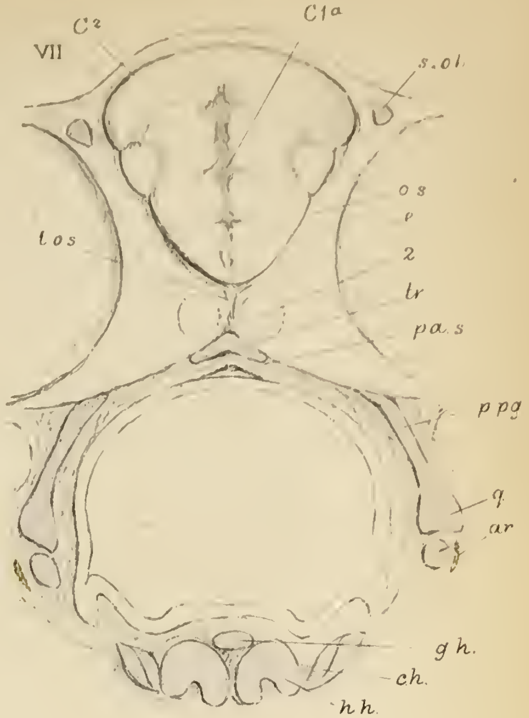
W West & Co. imp.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

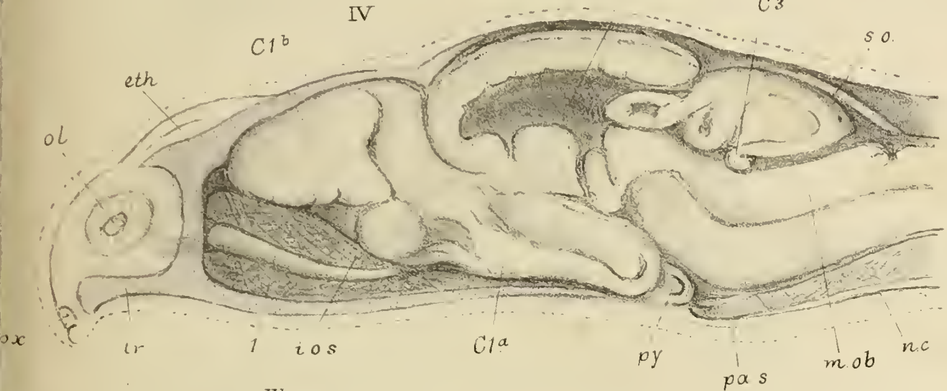
I



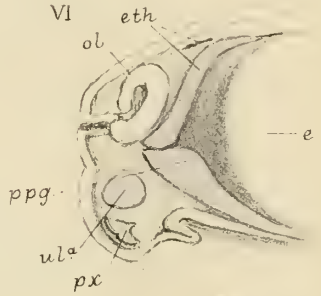
VII



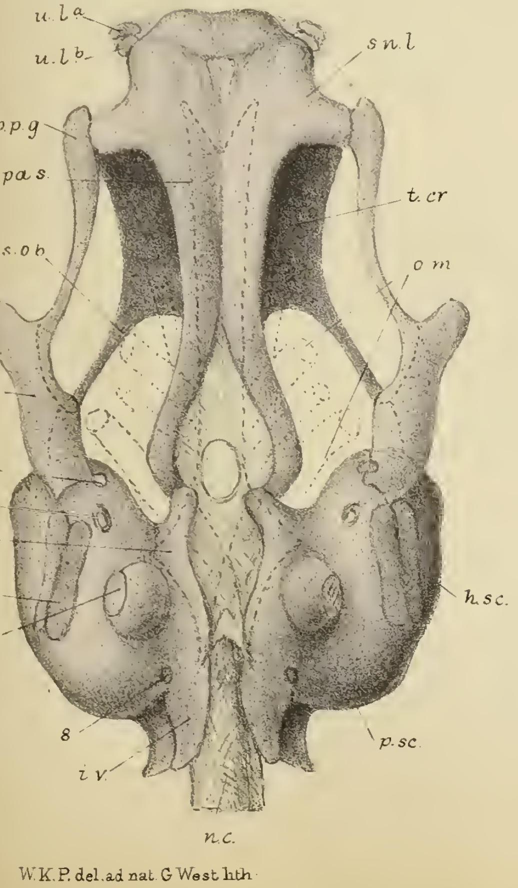
IV



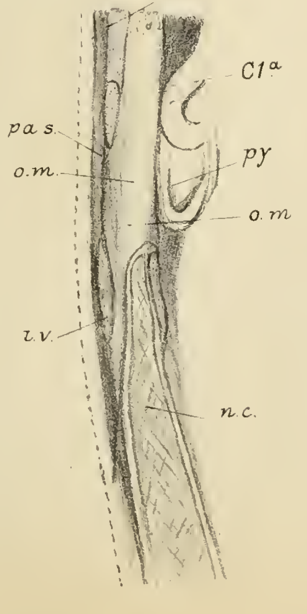
VI



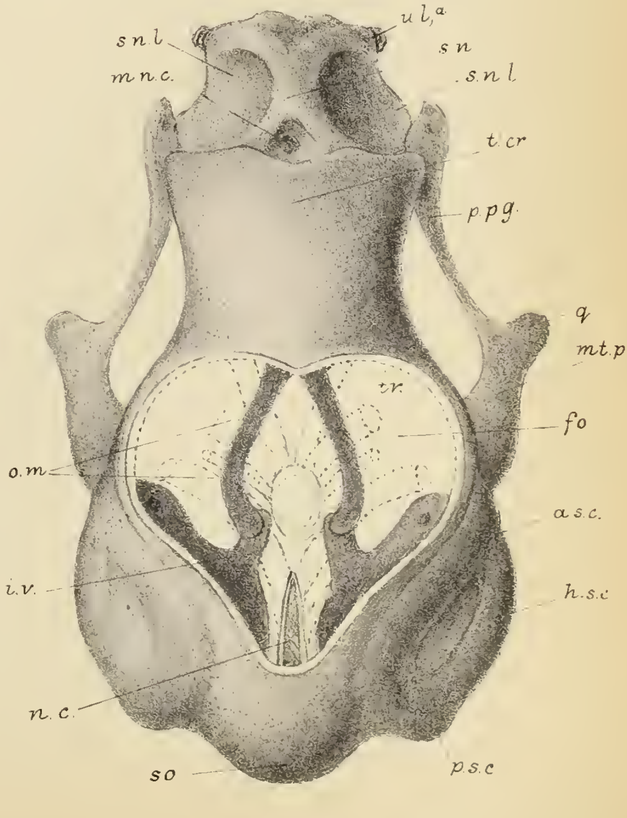
III



V



II.

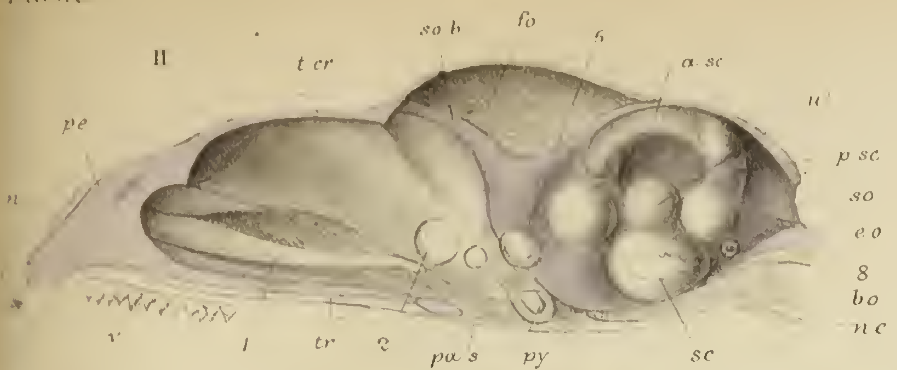


W.K.P. del. ad nat. G West lith.

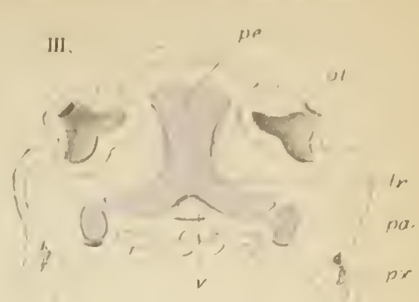
W West & Co imp

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

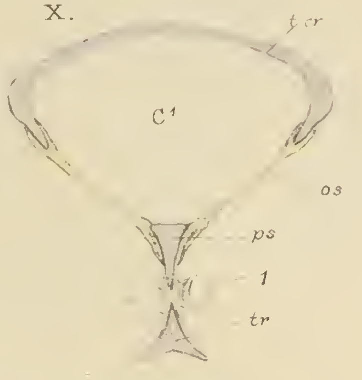
II.



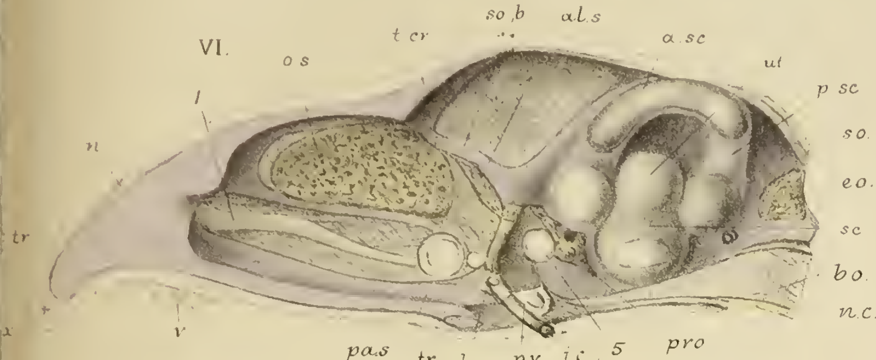
III.



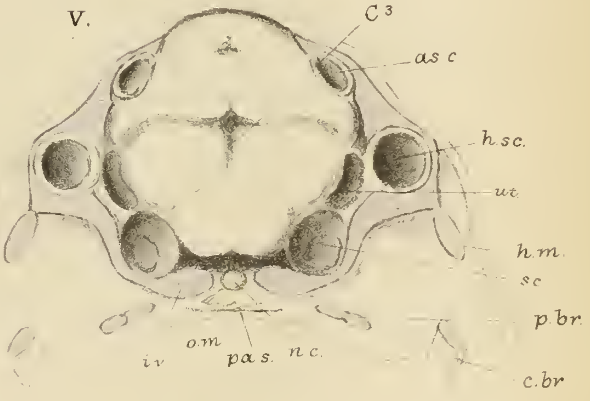
X.



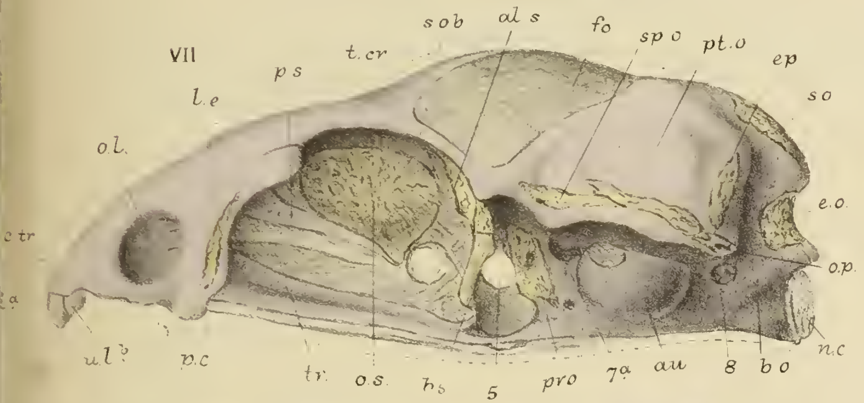
VI.



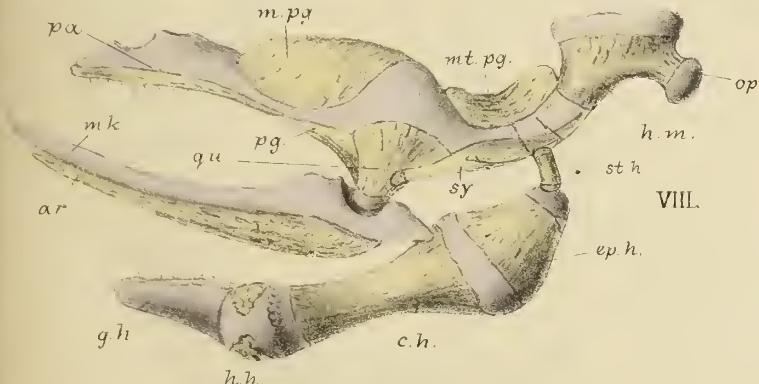
V.



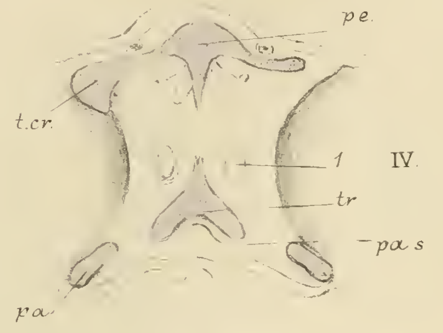
VII.



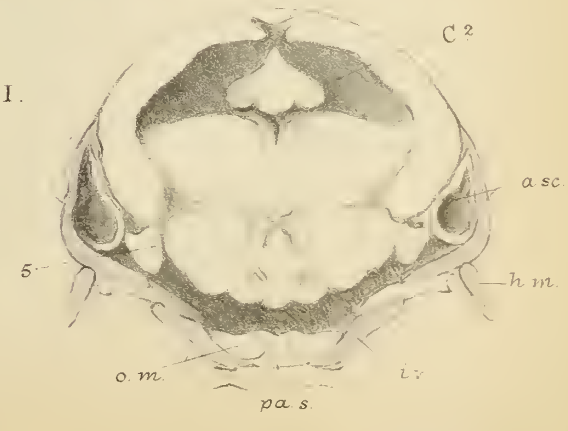
VIII.



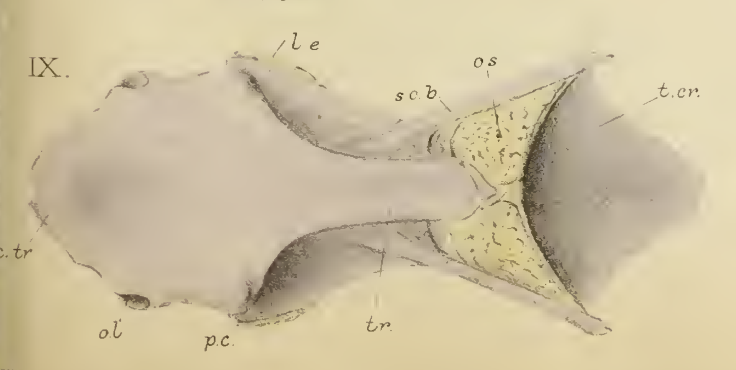
IV.



I.



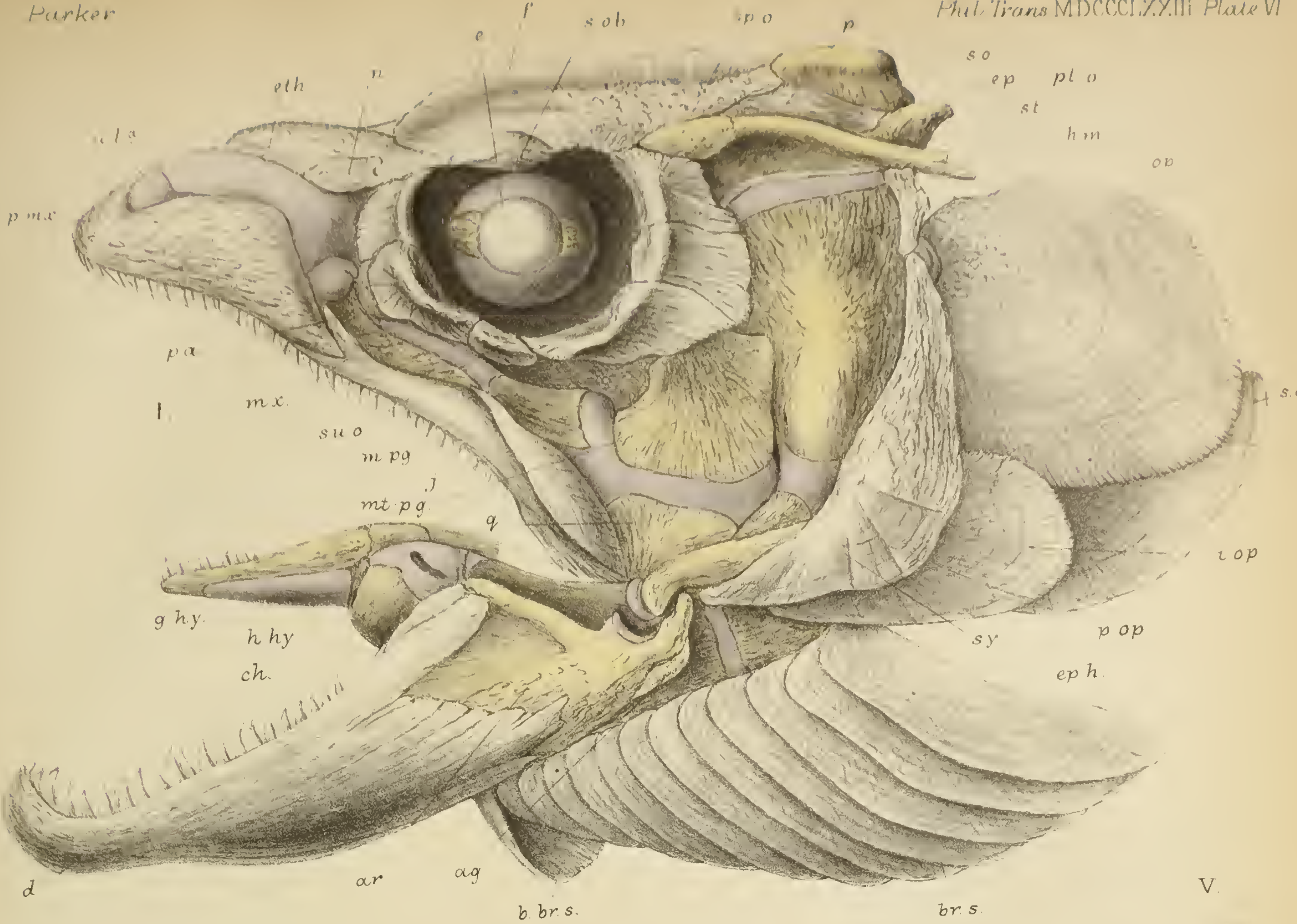
IX.

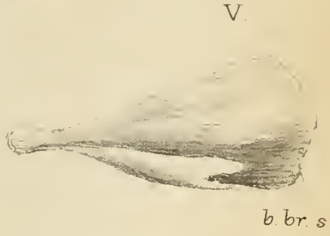


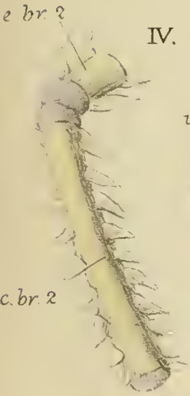
W.K.P. del. ad nat. G. West lith.

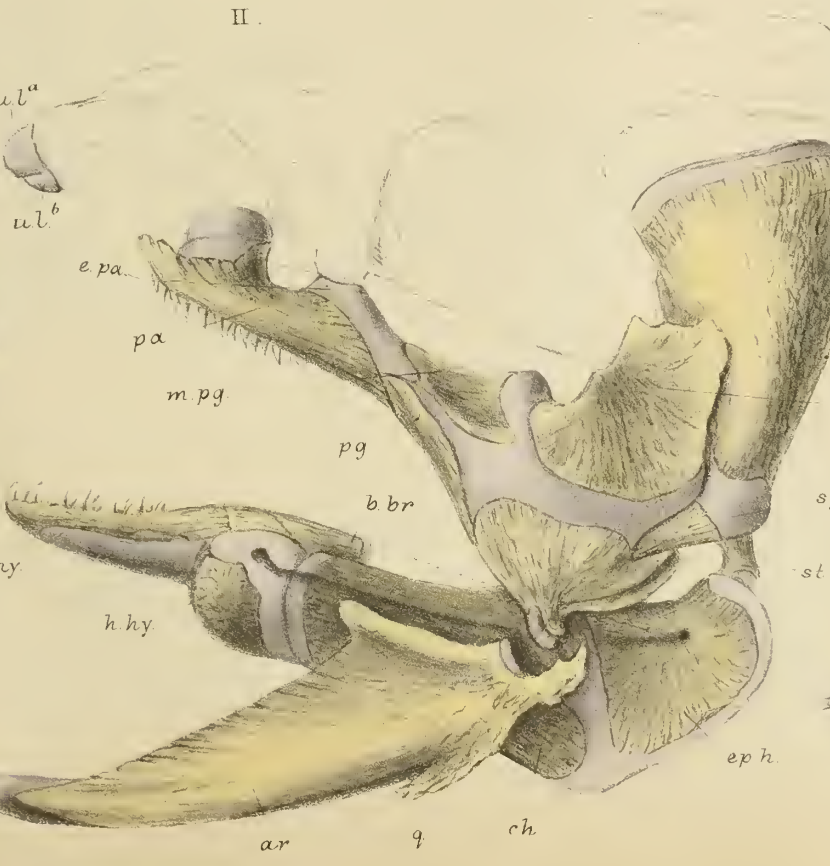
W. West & Co. imp.

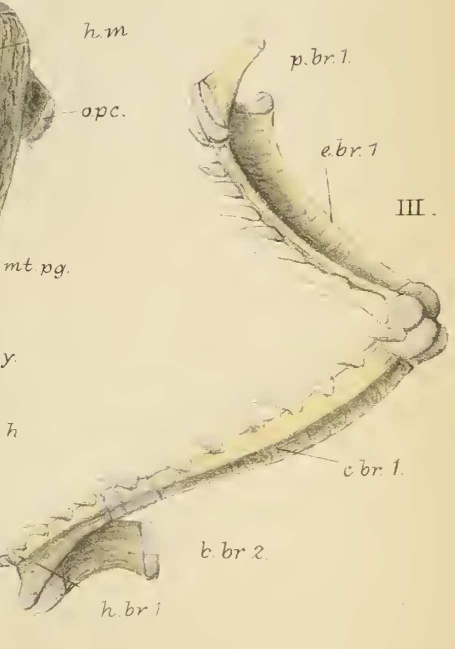
LIBRARY
OF THE
UNIVERSITY OF ILLINOIS


I.
e
f
s ob
p o
p
eth
n
s o
ep
pl o
st
h m
u l a
op
p mx
pa
mx
s op
su o
m pg
j
mt pg
q
i op
g hy
h hy
ch
sy
p op
ep h
d
ar
ag
b br s
br s


V.
b br s

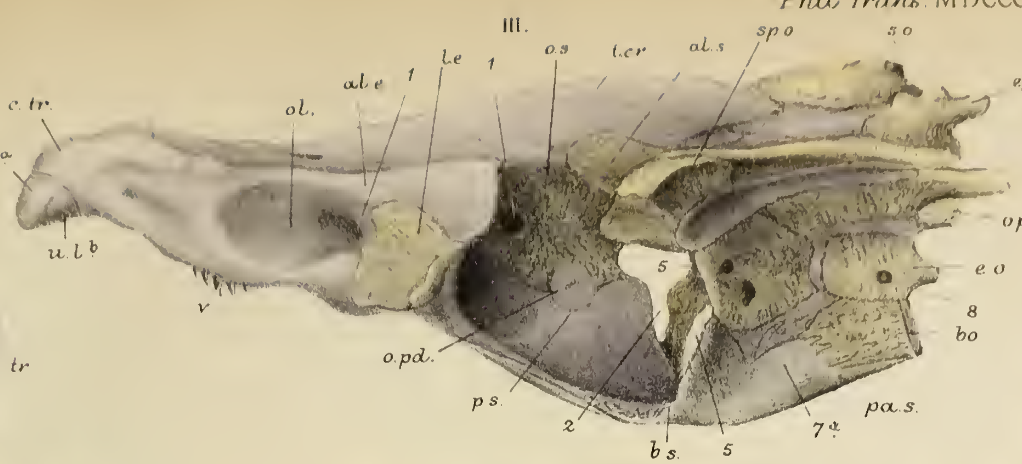

IV.
e br 2
c br 2


II.
u l a
u l b
h m
opc
e pa
pa
m pg
mt pg
pg
b br
sy
g hy
st h
h hy
m k
ep h
ar
q
ch

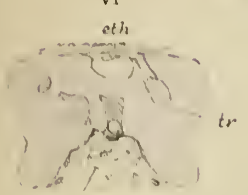

III.
p br 1
e br 1
c br 1
b br 2
h br 1

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

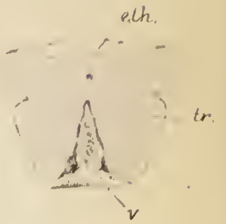
III.



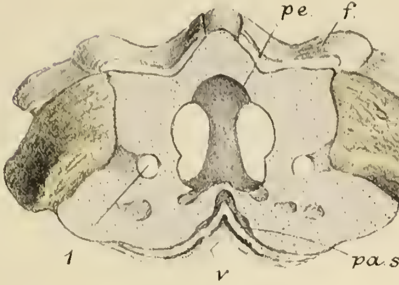
VI



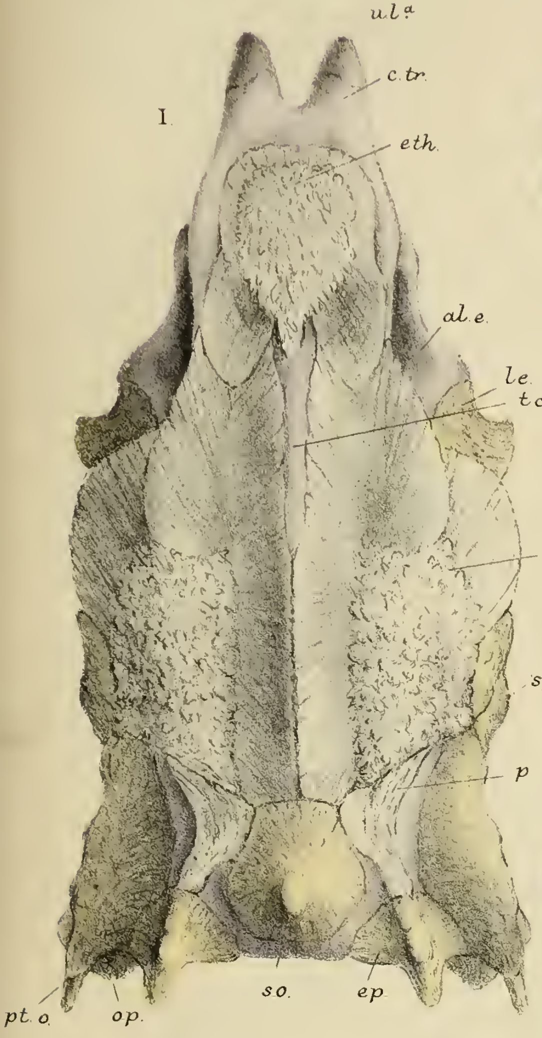
V



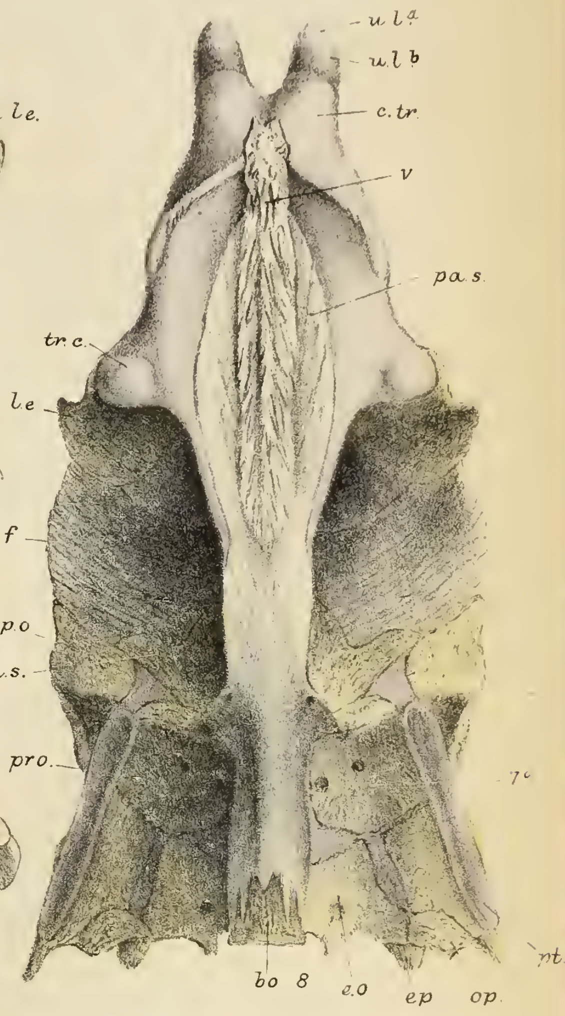
IX



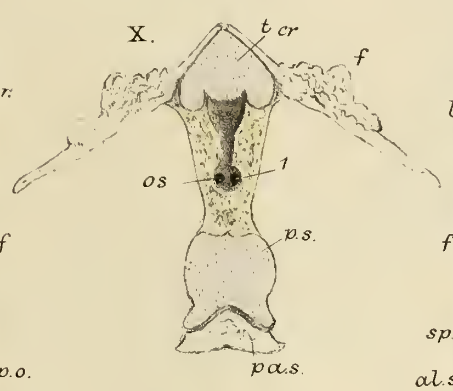
I.



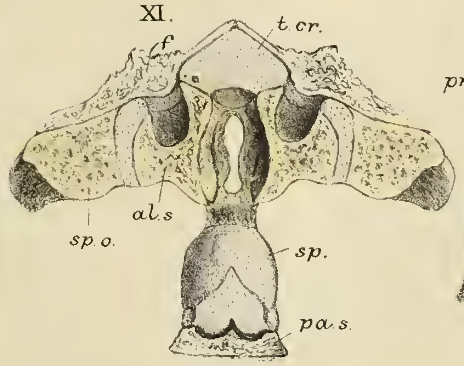
II.



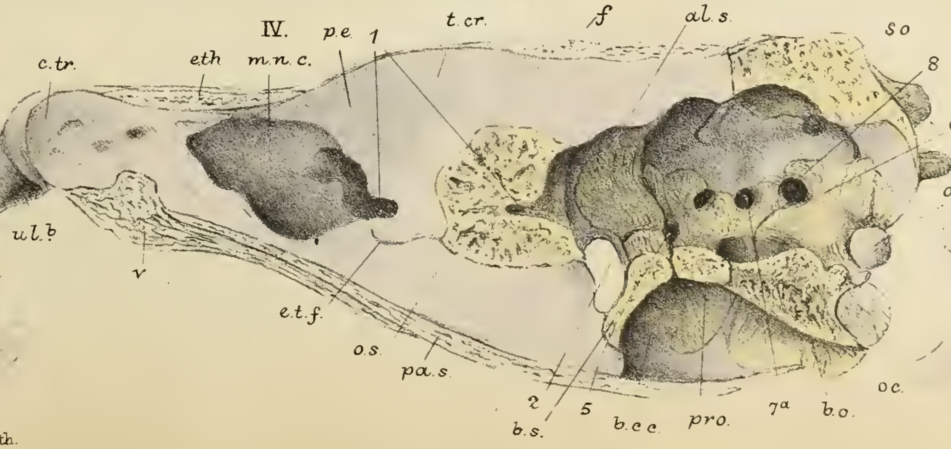
X.



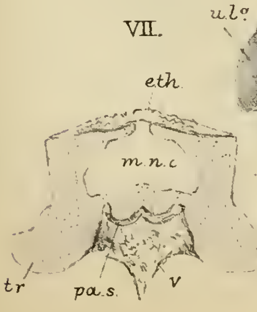
XI.



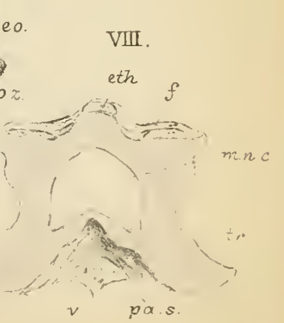
IV.



VII.



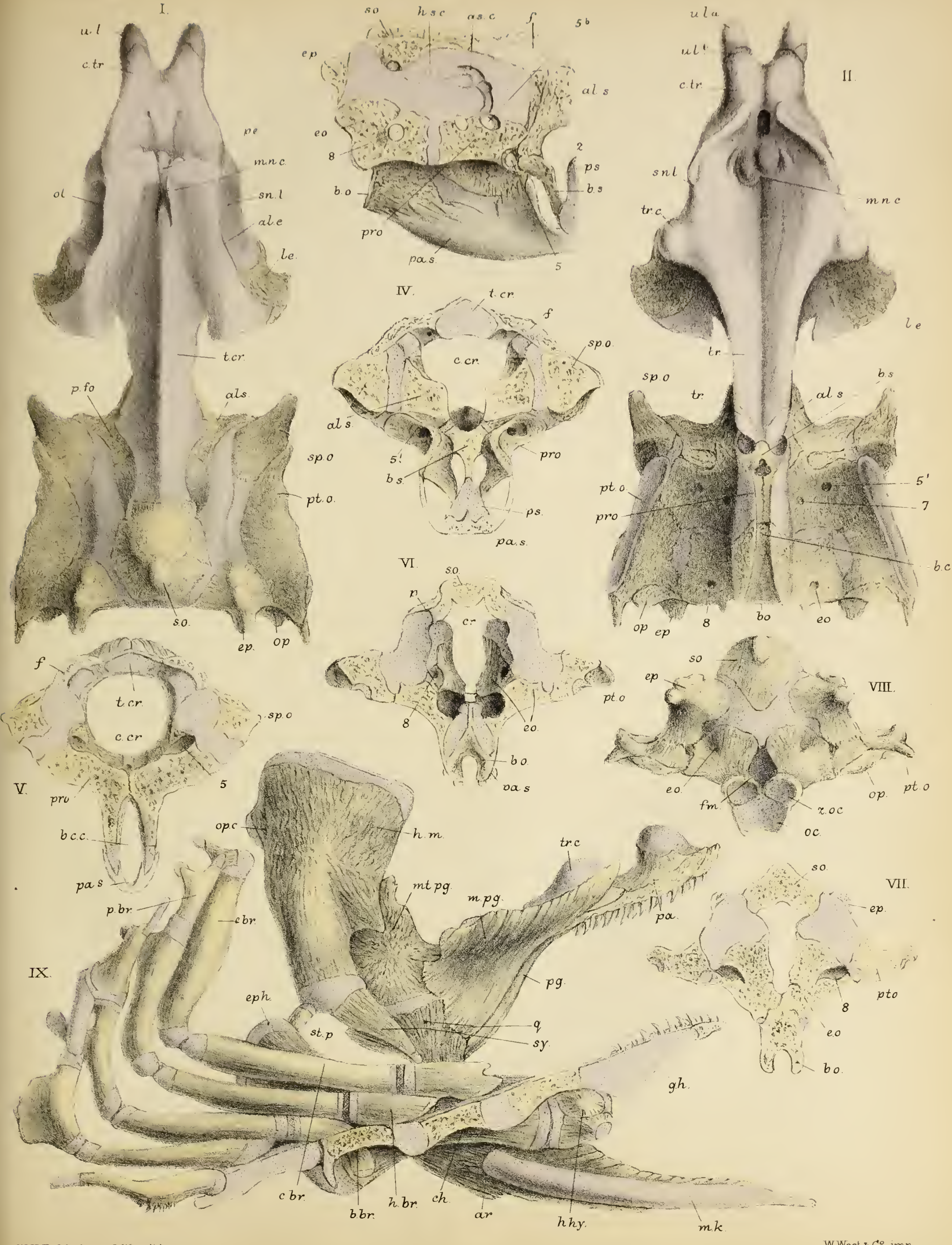
VIII.



W.K.P. del. ad nat. G. West lith.

W West & Co imp

LIBRARY
OF THE
UNIVERSITY of ILLINOIS



W.K.P. del ad nat. G. West lith.

W. West & Co. imp.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

Errata in Mr. MALLET'S *Paper on Volcanic Energy.*

Paragraph.	Line.	
186	7	*for* 63,536,524,001 *read* 63,536,524,001,280.
,,	8	,, dividing *read* multiplying.
,,	,,	,, 21,178,841,333,760 *read* 190,609,572,003,840.
,,	10	,, 3,272,370,686 *read* 29,358,710,136.
,,	11	,, $\frac{100}{4498}$, or less than $\frac{1}{45}$ *read* $\frac{197}{1000}$ or less than $\frac{1}{5}$ of &c.
,,	13	,, $\frac{40}{45}$, or less than 1 cubic mile *read* $\frac{40}{5}$, or 8 cubic miles.
188	11	,, 0·888 cubic mile *read* 8 cubic miles.
,,	12	,, 16·524 *read* 23,636.
190	9	,, $3 \times 0{\cdot}888 = 2{\cdot}664$ *read* $3 \times 8 = 24$.
191	2	,, 18·3 *read* 39·636.
,,	3	,, 18 *read* 40.
192	3	,, $400 \times 18 = 7200$ *read* $400 \times 40 = 16{,}000$.
193	3	,, *eight years* read *sixteen and a half years.*
194	5	,, 255 *read* 535.
,,	7	,, 7200 *read* 16,000.
,,	9	,, 255 *read* 535.
,,	33	,, 7200 *read* 16,000.
,,	34	,, 10,800 *read* 24,000.
196	6	,, 4,831,052,974 *read* 42,030,163,804.
,,	8	,, 746,481 *read* 6,234,079.
,,	,,	,, $\frac{1}{200{,}000}$ *read* $\frac{1}{23{,}612}$.
,,	11	,, ·000015 *read* ·000127.
,,	17	,, ·000315 *read* ·002667.
,,	19	,, ·000606 *read* 005577.
197	13	,, $\frac{300 \times {\cdot}000606}{3}$, $= {\cdot}0606$ *read* $\frac{300 \times {\cdot}00577}{3} = {\cdot}577$.
198	42	,, $\frac{1006390}{3^\circ} = 335463$ *read* $1006390 \times 3^\circ = 3019170$.
,,	43	,, 50·3 cubic yards *read* 466·5 cubic feet.
,,	44	,, $50{\cdot}3 \times 5280 = 265584$ million cubic yards *read* $466{\cdot}5 \times 5280 = 2463120$ million cubic feet.
,,	45	,, 2921424 million cubic yards *read* 27,093,226 cubic feet.
,,	46	,, 5842848 millions of cubic yards *read* 54,186,440 cubic feet.
,,	51	,, 2921424 *read* 1003452.
,,	52	,, 5842848 *read* 2006905.
,,	53	,, 9770662 *read* 4016747.
,,	55	,, $\frac{9770662000000}{5451776000}$, $=1792$ *read* $\frac{4016747000000}{545177600} = 737$.

III. *Volcanic Energy: an attempt to develop its true Origin and Cosmical Relations.*

By Robert Mallet, *A.M., C.E., M.R.I.A., F.R.S.*

Received May 13,—Read June 20, 1872.

1. Plutonic action has long been loosely applied by geologists as a term for forces of some sort, of whose nature little was known, acting deep beneath the surface of our globe, and either not directly manifesting themselves at all at the surface, or, if so, chiefly in the form of earthquakes, thermal springs, &c.; while volcanic action, showing itself at the surface in the phenomena of extinct, dormant, or active volcanoes, has been very generally regarded as something different in nature as well as in degree of activity. Some relations have always, more or less vaguely, been admitted between these; but each has in turn been placed in the relation of cause and effect to the other. A third class of actions, those of "forces of elevation," though assumed to have some relations with the preceding, have very commonly been regarded by geologists as differing in nature from both, in degree as well as in kind. It is true that all these phenomena have been linked together by such wide and vague phrases as that of Humboldt, who speaks of them as "the reaction of the interior of a planet upon its exterior;" but I am not aware of any attempt having previously been made to colligate them all as effects originating in one common cause, and that referable to the admitted cosmical facts and mechanism of our globe.

Sir William Thomson, regarding all these phenomena from the lofty point of thermodynamics (from which the writer also is about to view them in this paper), has distinctly colligated them as referable to dissipation of energy existing in our planet in the form of terrestrial heat, and has given to all its play of phenomena the title of "Plutonic action," which he defines as "any transformation of energy going on within the earth" (Trans. Geolog. Soc. of Glasgow, vol. iii. pt. ii.).

2. The writer accepts Sir William Thomson's above views, so far as he is yet acquainted with them through publication, as the broad basis for future physical geology.

Sir William Thomson, however, has not attempted, so far as the writer knows, to bring his general view, that volcanoes, earthquakes, &c. result from transformations of terrestrial heat, so to bear upon the facts known respecting these as to explain in any way the immediate mechanism from the play of which within our globe these grand phenomena of nature are produced; nor to connect these with the "elevation theories" of geologists, so as to substitute a precise and true one for the current and erroneous notions as to the nature of those forces which have elevated mountain-ranges and generally produced the inequalities of our globe, apart from the subsequent moulding-actions of water and other surface agencies.

The attempt to do this, in outline at least, which is all, perhaps, that existing knowledge admits of, is the object of the present paper. The term "Plutonic action" is objectionable, as already and long used by geologists in a loose and different sense. *Vulcanicity* is preferable, as proposed by the writer (4th Report on Earthquakes, Brit. Assoc. Rep. 1858), as comprehending all energy resulting either in volcanoes (*Vulcanology*) or in earthquakes (*Seismology*). In the former of these, forces of elevation generally may be comprehended, and in the latter thermal springs, though, as will appear when the intimate relations of the mechanism of all of these are better understood, the boundaries of these divisions at some points grow indistinct.

3. The phenomena seen at volcanic vents, and those experienced in earthquakes, have been tolerably well observed; and the immediate mechanism of the latter may be considered as understood, though the cause or causes of commotion, and it may be very different at different times and places, are still somewhat obscure.

The deeper mechanism of volcanic vents, all nearly except what is visible and tangible, is so far quite obscure; and this mainly because no rational origin has ever yet been assigned for the production of the high temperature manifested at volcanic vents.

To assign a true origin for this is to possess the key of the whole; for given a veritable cosmical mechanism for the production of the *heat* that shall square with its local distribution, and with the capricious, non-periodic phenomena of eruptive vents, and all the other observed phenomena of volcanoes, from the largest to the most minute of these, become explicable and fall into place upon a cooling terraqueous globe. As respects a presumed connexion, if not identity, save as to degree of intensity, between volcanic and seismic mechanism, however vaguely referred to some common force of origination, it can scarcely be said hitherto to have advanced beyond this.

Volcanoes, notwithstanding Von Buch's unsound distinction into linear and central groups, have long been observed to follow the lines of surface-elevations, *i. e.* mountain-chains, the exceptions being only apparent. (4th Report on Earthquakes, Brit. Assoc. Rep. 1858).

So also the writer has shown (Earthquake Catalogue, Brit. Assoc. and Seismic Map of the world thereof) that earthquakes on the whole are found to occur within the area of great seismic bands which follow and extend at either side of the mountain-chains of the world. Again, though thermal springs occur everywhere (just as earthquakes may occur anywhere), yet on the whole they are chiefly manifested in regions which have been or are greatly disturbed by mountain elevation or by volcanic and seismic activity.

Thus we find this local relationship binding together the whole, viz. that volcanoes, earthquakes, and hot springs follow the lines of mountain elevation or dislocation.

And this is almost all that we can certainly affirm connects them as having some common origin beneath.

4. Any subterranean impulse may produce an earthquake; and for those impulses there must be more than one nature of origin, for the impulse producing a shock like that of Riobamba cannot be the same as those producing the tremors of Pignerol or of Comrie, lasting for years.

Close to the volcanic vent the eruptive throes may produce earthquake-impulse before or after these have broken through the earth's surface; but we cannot *phenomenally* connect most earthquakes with volcanic action at all, inasmuch as there is, even in the very greatest, no local change of terrestrial surface-temperature.

We can only refer them to a common origin, if we can discover and describe some play of cosmical mechanism set in motion by terrestrial heat, that shall be sufficient in energy to account for all the phenomena, that shall bear examination when brought into contact with each particular class of well-ascertained facts, either of volcanoes or of earthquakes or of mountain-chain elevation, that shall leave none of these facts inexplicable, and that shall so link itself on to cosmical physics generally as to be applicable to like phenomena in other planets than our own, or satellites, so far as we have facts ascertainable in relation to these.

5. Within the limits of this paper it is impossible to enter upon any large discussion of the theories that have been advanced as to the nature and origin of volcanic activity and elevatory action; a few remarks upon the notions commonly current on these subjects amongst geologists are necessary, however, to point out their more salient defects and to contrast the views about to be here advanced with those which are current.

6. Volcanic theories have been always of two classes, the chemical and the mechanical. Omitting all earlier, DAVY's notion that volcanic heat was due to oxidation of the metals of the alkalies or earths by contact with water, supported by DAUBENY and in part by DE LA BECHE, is that which has mainly engaged attention. Had it not been for the splendour of DAVY's genius and the announcement of this view at the moment of his great discovery of the bases of the alkalies, it would probably never have had even a momentary acceptance.

DAVY himself abandoned it at a later period. When we remember that the mineral constituents in the rocks known in the earth's crust do not contain on the average more than about 4 or 5 per cent. of the alkaline metals taken together, and compare the nature of the total *ejecta* of volcanic vents, more especially those of gas or vapour as ascertained by many labourers, amongst whom must be distinguished DAUBENY himself, ABICH, BUNSEN, ST.-CLAIRE DEVILLE, and FOUQUE, with such as *must* result from DAVY's hypothesis, we can only wonder that one so absolutely gratuitous should ever have had a moment's acceptance.

There is no other "chemical theory" to put in its place. All great or violent chemical energies, powerful as these must have been in past time, when the materials of our planet were in vapour and dissociated by high temperature, have long since been as a whole satisfied.

7. As the thermal energy of the shrinking mass was dissipated, and it passed from vapour to liquid, and from that in chief part to solidity, the chemical energies of the sixty or more elements we know of became satisfied by combinations, the order and conditions of which chemistry may yet hope to trace, though it cannot do so at present*.

---

* STERRY HUNT and STONEY have, however, made the attempt.

8. That there now exist in the interior of the earth large masses of uncombined metals of great specific gravity and high fusing-point, and strongly electronegative in the chemical scale, as gold and platinum, to which we may add iron if its vapour existed in large excess in the original *nebula*, is highly probable, both on such speculations as we can so far form as to the order of the play of chemical forces during the globe's formation by condensation, and as perhaps the only way in which the earth's mean density can be reconciled with that of its known superficial crust.

But the chemical elements composing that crust are on the whole in a state of combination; and hence no chemical energy remains stored up for conversion either into heat or into work.

9. For we may obviously, in relation to vulcanicity, pass by those minute chemical changes at present going on within the crust, mainly through the action of air and water and matter dissolved therein on some of its various constituents. We may even omit as insufficient whatever of chemical action took place during the period (probably yet not *quite* ended) when the mineral lodes or veins were formed. In a word, the chemical elements of the crust and interior of our globe, so far as we know any thing about them, have long assumed a state of chemical equilibrium, and one generally of the most stable character. So that we are compelled to conclude that whatever evidences of chemical decomposition or combination may be presented to us by the ejecta of volcanoes, the chemical action has been brought about by elevation of temperature at the seat of action deep below.

10. That thermal energy has been in part transformed into chemical work and not chemical energy into heat. There is therefore no room longer for *any* "chemical theory" of volcanoes; and we are reduced to that commonly, though not quite accurately, called the mechanical one. This has passed current at different times in several forms, but all resting upon the assumption that our planet now and for long past consists of a liquid nucleus of fused matter at a very high temperature, covered by a solidified crust of matter chemically much the same, but the materials of the uppermost strata of which at least have been dislocated, broken up, redeposited, and variously arranged into surface formations by the long-continued action of those superficial agencies with which the geologist deals.

11. The hypothesis of the existence of a liquid *nucleus* intensely hot rests mainly upon two grounds:—1st, the nebular origin of our globe in common with all others, as suggested by LAPLACE, by which the interior of a cooling globe must be *hotter* than the exterior; 2nd, the observation of temperature, which proves to increase with the depth, though in a very discordant sort of way.

12. That our globe is *hotter* within than on or near its surface is *a fact*, but that it possesses a liquid nucleus in a state of fusion is only an hypothesis, though a very probable one. The rate of increment of temperature with depth, far too hastily assumed to follow everywhere one simple arithmetic law, and the facts of terrestrial conductivity, so far as these are known, induced the belief that the solid crust is comparatively thin.

An unlimited supply of liquid lava was thus provided; the question was, what brought it up through this thin crust, and ejected it and other matters at the surface. By some, amongst whom Signor BELLI may be distinguished for the ability of his writings, the crust was assumed so thin as to merely float upon the liquid globe beneath; and a mechanism being conceived for fracturing the crust into separate fragments, and their density being rather greater than that of the supporting fluid, these sunk more or less in the latter and forced up the liquid lava in the spaces between.

13. This, which may be called the hydrostatic theory, has had several modifications. Another school of geologists, and the more numerous one, assumes that infiltrated water reaches the liquid and incandescent nucleus at certain points, and that by the elastic force of the stream formed the lava and other *ejecta* are forced up; and this, too, has had several modifications.

These latter views are no doubt true so far as the general notion of ejection by steam pressure is concerned; but insuperable difficulties appear to arise against the origin of the incandescent matter coming from one great reservoir, common, therefore, to all the volcanoes on the earth.

14. There is no evidence of universal connexion with such a common source of liquid rock beneath.

On the contrary, volcanic vents even closely adjacent show no proofs of direct intercommunication.

Their efforts are not synchronous; their paroxysms are isolated and subject to no recognizable periodicity; their ejecta, solid, liquid, or gaseous, though showing a great general similarity in all parts of the world, are far from being identical in chemical constitution or in temperature; these vary at different times, and show signs of secular change in geologic time.

The liquid or solid ejecta show no such uniformity at *all* volcanic vents as should arise from their coming all ready fused from one universal reservoir, the contents of which, at the same depth, it has been supposed there is no ground for assuming to differ in composition; while they *do* show very distinct indications of having some relation to the rocks directly through which the vents pierce, or over which they are posited.

None of these difficulties, to which others of a not unimportant character might be added, have ever been explained away.

15. A further difficulty was placed in the way when the investigations taken from astronomical considerations were supposed to prove that the earth's crust, instead of being very *thin*, must be very *thick*. It was not inconceivable that the liquid rock of the nucleus might in some way reach the surface through ducts or fissures in a shell of 20 or 60 miles thick; but it was at least more difficult to conceive, if not quite inconceivable, by what force and how it should be propelled through ducts of 800 or 1000 miles or even more in depth. It is quite a separate question what degree of weight should be attached to the celebrated paper by the late Mr. W. HOPKINS, F.R.S., on Precession and Nutation, as proving a thickness of solid crust exceeding 800 miles or so.

The difficulties to his reasoning, arising from his neglect of viscosity and friction-hold between the solid crust and the liquid nucleus at the surfaces of contact, have been forcibly stated by M. Delaunay (and have certainly been underrated generally, and, indeed, have only been met by the mathematicians who have been the partisans of Mr. Hopkins's views), by showing that if the physical difficulty of such viscosity &c. be admitted, other mathematical difficulties must arise if we cling to the method of Mr. Hopkins as capable at all of giving any answer to the question of thickness of the earth's crust, which the writer believes it is not. That that thickness is not small, however, the writer believes to be the fact upon considerations wholly different from those of Mr. Hopkins; and that view receives support from the investigation of Sir William Thomson as to the rigidity of the earth, at least with those who admit the sufficiency of the physical data upon which his mathematical reasoning there is founded. The effect, however, of this conjunction of the reasonings of the physical astronomer and of the geologist has been to raise a new difficulty for both.

16. The geologist, chained down under 800 miles or more of solid rock, the real thickness of which he is in no condition to *disprove*, cannot get his liquid lava sea beneath to the surface; and he has no other source for volcanic heat and ejecta to suggest.

The mathematician has the *fact* before him; volcanoes exist. He admits the difficulty of the geologist, and meets it by the most lame and gratuitous hypothesis of lakes or isolated masses of liquid fused rock existing at different points and at different depths (which depths, however, must, on the whole, be shallow within the solid crust of the earth), and assumes that from these the volcanic vents are supplied.

17. Nothing can be more feeble and unconvincing than the attempt made by Mr. Hopkins to give a rational explanation or support to this gratuitous and most improbable hypothesis, which, so far as the writer knows, that gentleman was the first to bring forward in his "Researches in Physical Geology," 2nd series, Phil. Trans. for 1842, Part II.:—"We are necessarily led," he says, "therefore to the conclusion that the fluid matter of actual volcanoes exists in subterraneous reservoirs of limited extent, forming subterraneous *lakes* and not a subterraneous *ocean*" (p. 51). He adds (same page), "If we find that the hypothesis of the existence of these subterranean lakes, at no great depth beneath the surface, does enable us to account distinctly and by accurate investigations founded on mechanical principles for the phænomena of elevation . . . . . then we have all the proof of the truth of our hypothesis which the nature of the case will admit of."

That is to say, if we admit Mr. Hopkins's physical notion of elevatory force, viz. that it consists of the pressure vertically upwards of a fluid against the superincumbent solid crust, we may also admit his lakes. If, however, as we shall presently see, Mr. Hopkins's fundamental conception of the nature of elevatory forces is erroneous and untenable, then the lake-hypothesis must stand alone and upon its inherent improbabilities. At p. 52 the only attempt made to produce a rational origin for these supposed fiery lakes is thus given:—"It would seem probable, I think, that their origin may be ascribed to the greater fusibility of the matter composing them; and their continuance in a state of fluidity may, I conceive, be accounted for partly by the same and partly by another, which I will proceed to explain."

This other cause, which occupies pages 52 and 53, is simply another hypothesis, that if the pressure of the superincumbent dome over the liquid lake be removed, partially or wholly, by its becoming a self-supporting dome or arch, then the relief from pressure thus arising must lower the fusing-point of the liquid material of the lake, and so keep it longer liquid.

18. There is nothing absolutely in any of the known facts as to the materials of our earth's crust to warrant our supposing isolated masses therein of far greater fusibility than the remainder, to say nothing of that material being *ex necessitate* penetrated by water from the surface, to which it is admittedly near; for without the water we can have no volcano. Other serious difficulties occur as we attempt to follow out this notion by a comparison with observed facts of volcanic action at the vents, for which space cannot here be afforded. We pass on to some remarks on the theories of elevation.

19. The words "elevation," "upheaval," "*Aushebung*," "*soulèvement*" have been continually employed by the geologists of all countries, but especially of our own, in the loosest way, so far as the forming of any definite conception of the play of forces or mechanism of the movements is concerned.

A wide survey of the writings of geologists proves, however, that the notion generally formed of a "movement of elevation" is that it is produced somehow by a force acting beneath a limited area and in a vertical line, or nearly so, and in a direction from below upwards. Commonly it is assumed or inferred that the pressure upwards, beneath the area "elevated," has been that of a fluid, gaseous, as by Von BUCH &c., or more or less perfectly liquid, as by most others.

20. It is true that some geologists (amongst whom was the late Mr. JUKES) had some not very clearly defined notions that such machinery of elevation would not account for the facts as to elevated masses observable in nature, especially the frequent smallness of area in relation to the abruptness and height of the masses elevated.

But that this notion, that elevation is produced somehow by nearly parallel forces acting radially to the spheroid, is even yet the one commonly maintained we need no proof beyond turning over the pages of the latest writers on geology. If we look at the figure on page 285 (2nd edit., 1862) of SCROPE's 'Volcanoes,' we shall see evidently that such is the notion he formed; and, without citing further examples, it is that which HOPKINS distinctly enunciates as his fundamental conception of the matter in his paper on "Researches in Physical Geology" (Trans. Cambridge Phil. Soc. vol. vi. part i.), where he says (p. 10):—"The hypotheses from which I set out, with respect to the action of the elevatory force, are, I conceive, as simple as the nature of the subject can admit of. I assume this force to act under portions of the earth's crust of considerable extent at any assignable depth, either with uniform intensity at every point, or, in some cases, with a somewhat greater intensity at particular points—as, for instance, at points along the line of maximum elevation of an elevated range, or at other points where the actual phenomena seem to indicate a more than ordinary energy of this subterranean action. I suppose this elevatory force, whatever may be its origin, *to act upon the lower* *surface of the uplifted mass through the medium of some fluid*, which may be conceived to be an elastic vapour, or, in other cases, a mass of matter in a state of fusion from heat. Every geologist, I conceive, who admits the action of elevatory forces at all will be disposed to admit the legitimacy of these assumptions." The first effort of our elevatory force will of course be to raise the mass *under which it acts*, and to place it in a state of *extension*, and consequently of *tension*.

21. If this fundamental notion be (as the writer believes it is) erroneous and opposed to all the facts observable in the great regions of elevation, *i. e.* in the mountain-chains of the world, then it must be admitted that the speculations which follow as to the formation of fissures &c. (in a word, the substance of the doctrines of this paper, however ingenious as a mathematical exercise) have no true reference to the facts as occurring in nature, and, promulgated with the authority of the author and with that sort of oracular sanction which mathematical symbols possess for those who are devoid of mathematical knowledge, have tended materially to retard the progress of a truer interpretation of elevatory forces.

22. If we were to assume (as has been done) that the appearance of the masses of the great continents above the sea-level was a work of elevation at all, it might be a case to which Mr. HOPKINS's notion could perhaps apply. But that the great continents have not been the work of such elevatory forces at all, but have resulted from the *deformation* of a cooling and contracting globe covered only by a thin and yet flexible solidified crust, sinking over great areas and relatively or absolutely rising over others, has been so convincingly urged by DANA and other American geologists that it is probably now admitted.

23. DE LA BECHE's notions as to elevation approached nearer to exactness than those of most of his contemporaries*; but to one man alone, CONSTANT PREVOST, belongs the honour of having clearly enunciated a true theory of elevatory forces, followed out by comparison with facts in nature, and by showing that these were inexplicable upon the notion of direct upheaval by a radial force from beneath.

---

* [To cite even by name all the authors whose works contain scattered passages from which notices may be gleaned (always more or less vague, disjointed, or even inconsecutive) as to the relation between terrestrial refrigeration and the formation of continents, mountains, &c., is here impossible. DE LA BECHE, in his 'Researches in Theoretic Geology,' 1834, pp. 121–162 *et passim*, writes far more clearly and connectedly than others of that period. His views, however, were anticipated by PREVOST. Those who desire to trace more fully the history of this branch of knowledge will find somewhat ample references to past authors in an able paper by Prof. DANA, "On the Geological Results of the Earth's Contraction," in Amer. Journ. of Science, 1847, vol. iii. ser. 2.

The leading idea of the present Paper (namely, the showing that the deformations producing continents and sea-beds, the elevation of mountains and depression of valleys, and the origination of volcanic heat and energy are all due to a unique cause at different stages of its long-continued action) could not have been anticipated by any of the many eminent men above referred to, by DANA or by the writer, because the imperfect state of the science of Thermo-Dynamics down to a later period rendered the leading idea itself impossible to them.]

N.B. Passages in the text or footnotes which, like the present footnote, are enclosed in brackets were inserted in March or April 1873.

24. The nature of the conception of this force, as more or less clearly shadowed forth by geologists, admits of no doubt, as regards French geologists at least, when we consider the force of their adopted term *soulèvement* (presumably *sublevare*, *sous-lèvement*, a lift by a force from beneath), and, indeed, is pretty evident in the German *Aushebung*; but the English "upheaval" and "elevation" admit of any cloudiness of conception or latitude of interpretation.

25. PREVOST'S ideas are scattered through numerous papers, extending over nearly twenty years, but are to be found in their most systematic and formal manner in vol. xxxi. part ii. of the 'Comptes Rendus' for September 1850, p. 461 *et seq.*, and, at an earlier period, in the 'Bulletin de la Société Géologique de France,' vol. xi. p. 183 *et seq.* His view is this, that, apart from the great deformations which hollowed out the ocean-beds, as to which he is not quite so clear, all elevations of the earth's surface of the nature of hills or mountains (in general the rugose contour of its surface) have been produced, not by vertical forces directly coming from some unknown deep-seated source, but by vertical forces, the *resultants of tangential pressures*, acting against each other in horizontal or nearly horizontal directions, and transversely to the ridges or lines of elevation, these tangential pressures originating in the contraction of the earth's crust by secular refrigeration. This view, which the writer believes to be true, has been followed out by DANA, the two ROGERS in America, by ELIE DE BEAUMONT and some other continental geologists, by showing how completely the observed facts fall into place and are accountable for by it, but oppose themselves to the notion of a vertical primary force.

26. The Rev. O. FISHER also, in an important paper "On the Elevation of Mountain-chains, and Speculation on the Cause of Volcanic Heat" (Cambridge Trans. vol. xi. p. iii, 1868), which the writer had no knowledge of until after the present paper had been written, has given support to PREVOST'S view, by proving the mechanical adequacy of the tangential pressure due to refrigeration to the elevation of the highest mountains of our globe.

Mr. FISHER'S views in the above paper as to the origin of volcanic heat are entirely different from those of the writer as here developed.

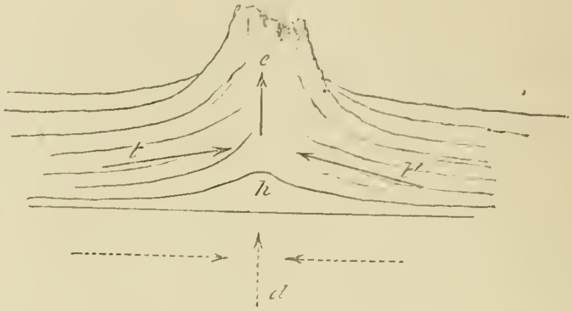
27. Upon HOPKINS'S view, all elevated parts must have *convex* surfaces, and, whether continents or ridges steep as the high Alps, must be *bombé* or dome-like in contour; they must all present the evidences of *tension* during elevation and in orthogonal directions. But the careful geological surveys and sections made since PREVOST'S day show that, on the whole, the sectional contour of large areas, much less those of continents, are not *bombé*, and that the transverse sections of all mountain-ranges prove their curvatures on opposite flanks to be not convex, but concave—a form which is generally the case in the fall of the land from all mountain-crests to the sea-level, as is evident by the concave form (approaching to something of a curve of the parabolic order) shown by the longitudinal section of all large river-courses.

28. The "fan-like" structure of the Alps (*structure en éventail*), so well elucidated by FAVRE and STUDER, VON LINTH, and other Alpine geologists, becomes a conclusive proof alone that the forces of elevation have been lateral compressions resolved into the

vertical. Thus the deficiency in density more recently found, or with good grounds suspected, as occurring beneath great mountain-masses receives its solution, whilst a greater density there would be the necessary result of direct vertical pressure.

29. Thus it is evident that the tangential, or nearly tangential, and opposing pressures t and t', resolved into the vertical e, by which the upraised mountain-mass is lifted, tend to reduce the density, if not to leave actual hollows, about h, *below* the level of the intersection of those three lines of force and *above* that at which the tangential forces are completely horizontal; but that a directly vertical lift, as by d continued on by e to the summit, must tend to produce increased density about h.

Fig. 1.



30. The intense plications and foldings over of strata and *absolute overturn* of whole mountain-masses, seen in all great regions of elevation, the tremendous bending, foldings over, and smashing up of beds, such as M. Burat's sections of the Coal-formations of Central France or those of D'Halloi and Von Dechen of the formations of Belgium and of Westphalia, become thus accountable for, as are, indeed, all the salient phenomena presented by the surface and sections of our earth's crust, to follow out which in detail here is impossible.

31. One or two important results which follow from Prevost's grand hypothesis, that all forces of elevation, in a word, the only known vertical lifting agent (volcanic vents excluded), are resolved or transformed tangential forces of compression due to contraction, and acting in antagonism at various but no very great depths beneath our globe's present surface, which as yet have attracted no attention, should be at least alluded to.

32. These tangential forces of compression, acting slowly, not at all points uniformly or alike at all times, and on the whole (as the globe cooled) with a diminishing intensity, act simultaneously, though unequally, over great areas of sectional surface of the earth's crust. Relatively to the tremendous crushing-power of the tangential forces themselves and to the long continuance of their action, the materials on which they act must be viewed as more or less plastic.

33. It follows that if by resolved tangential pressures acting against each other in one direction, or in parallel directions along lines or in planes, elevations are produced, the *compressions* in these directions must be accompanied by extensions in the orthogonal directions, by difference in resistance to pressure producing tensions.

34. Hence, by the final resolution of tangential compressions, surface-*fissures* may follow from these orthogonal tensions, so that generally the compressions shall give rise to crumplings up and crushing together of strata, to elevation, and to fissuring; in which last the phenomena may *simulate* the effects of direct elevatory forces, according with Hopkins's hypothesis. And this is the reason why the actual directions of observed

fissuring in nature do, to a certain extent in one set of directions only, viz. in those orthogonal to the lines of horizontal pressure, coincide with those assigned by Mr. HOPKINS. But it further follows, admitting the relative plasticity of the less coherent formations of our earth's crust and the sufficient power of these tangential pressures for crushing up the others, that not only elevation may result from their vertical resolution, but that conditions must arise where these pressures act through considerable depths of materials differing in nature or in resistance, or in both, so that, by other analogous resolutions into the vertical or more or less toward it but in the opposite sign (*i.e.* downwards), *depressions* and hollows of any sort of form are producible.

35. Also that when these tangential and compressive forces, taken in a horizontal plane, make an angle in meeting greater or less (as may also happen in a vertical plane), then lateral displacements and all the phenomena of shifted strata or interrupted veins or faults can be produced.

36. We can also see that this view of the origination of the elevatory forces which have raised up our vast mountain-chains at once assigns a true and adequate cause for a limitation to their possible height; for as soon as the mass *already forced up* presses by gravity downwards upon the resolved vertical force e (fig. 1) to such an extent as to equal the resistance to crushing of the rocks beneath in the directions t and t', the further effect of the tangential pressures in those directions must be expended in crushing the rock between them to powder, where in some direction the solid can yield unequally, or in forcing off the material in some other direction than in the vertical. It is difficult to see how any limit is assignable to mountain altitude upon Mr. HOPKINS's hypothesis, unless by calling in other hypotheses for limiting the uplifting force itself, the intensity of which we cannot estimate in his case, inasmuch as its very nature is left unknown.

37. If, then, in PREVOST's notion we find an adequate and consistent theory of elevatory forces, it is the writer's belief that in it also (when followed to its legitimate consequences in one direction) we possess the clue that shall ultimately lead us to an equally simple, adequate, and consistent theory of Vulcanicity as here about being unfolded.

38. That the globe is hotter as we descend into it may be accepted as a fact, even from the very limited number of trustworthy experiments we yet possess; for artesian wells and small borings are alone to be relied upon, mines and coal-pits giving (for reasons not necessary here to enlarge upon) unreliable results.

39. And as we are certain that the geothermal *couche* of uniform annual temperature is everywhere above the existing temperature of the celestial spaces, so our planet must be a *cooling globe*; and if so, in accordance with all we know of the materials of which it consists, a *contracting globe*.

40. The rates of increment of temperature with depth, however, present great discordance even after we have excluded cases (such as mines or coal-pits at work) likely to contain accidental sources of error. Not only does the rate vary from 1° Fahr. in 15 feet of depth to 1° in more than 200 (MALLET, 'Neapolitan Earthquake Report,' vol. ii. p. 310), but in places within a mile or two of each other, and in the same formation, it varies as much as from 208 to 83 feet for 1° Fahr. (*op. cit.*). Even in the same vertical line of

boring the rate of increment has been found to vary at different parts of the descent. A large proportion of the observed temperatures certainly fall within the limits of 1° Fahr. in 30 feet and in 60 or 70 feet of descent.

The most complete and valuable collection and discussion of all the observations on record up to June 1836 which the writer has met with is to be found in a rare and scarcely known Inaugural Dissertation for the degree of Doctor of the Rheno-Trajectine Academy (4to, 101 pp., Müller, Amsterdam, 1836), entitled "Disputatio Physica Inauguralis de Calore Telluris infra superficiem augescente," by A. Vrolik. The careful and laborious author places the following amongst his general conclusions:—"Variarum observationum autem eventus, adeo inter se discrepare ut certam incrementi legem pro unaquaque regione nondum statuere possimus." He believes it proved that in general the rate of increment is greater in plains and valleys than in mountains.

41. These conclusions have been sustained by the later observations made since 1836. De la Beche, Herschel, and Babbage enunciated more or less clearly a connexion between the increment of hypogeal heat and the conductivity of the superposed strata.

That was afterwards examined carefully by Hopkins in one of his most valuable memoirs, that "On the Conductive Powers of various Substances, &c." (Phil. Trans. vol. cxlvii., 1857). Towards the conclusion he remarks, "On the whole, then, I cannot avoid the conclusion that the existence of a central heat is not sufficient in itself to account for all the phenomena which terrestrial temperatures present to us" (p. 835); that is to say, that a cooling globe, together with such effects as his experiments on conductivity of its materials warrant, are still insufficient to account for the observed discrepancies in hypogeal increment of heat.

42. One great source (if not the only one) for the unknown residual phenomena thus distinctly indicated by Hopkins we hope presently to point out, and to prove its intimate connexion with existing volcanic phenomena.

43. Our present knowledge of hypogeal temperature, while thus and so far insufficient to sustain any very minute conclusions based upon annual absolute loss of heat by our earth, seems surely to support the fact that our earth is a cooling globe; while astronomical analogies and considerations of its figure seem equally to warrant the presumption that it has been a cooling globe at all times from a state of fusion; and if so, that from that period and up to the present it has been on the whole a contracting globe.

These are all the conditions we require to admit for the conclusions to be obtained by considering the sequence of the phenomena that have followed on refrigeration.

44. It may be remarked, in passing, that the general credence of geologists in the cooling at all of our globe has been more or less disturbed by the celebrated memoir of Laplace (Mécanique Céleste, tom. v. cap. iv. p. 72 &c.) "On the Cooling of the Earth as affecting the length of the Day," in which it has been taken for granted, by most geologists at least, that the great mathematician has irrefutably proved that our globe has not cooled sensibly for the last 2000 years.

45. With due reverence for the intellectual sovereignty of Laplace, the writer ventures

to suggest that his calculation really proves nothing as to what may be the actual facts in nature, because the physical data which he has employed are not such as actually occur in nature. The law of compression with depth adopted was objected to by Dr. YOUNG; and the assumption that the coefficient of contraction is the same for the entire globe, whether liquid or solid, hotter or colder, seems to vitiate the results.

If a colder and consolidated crust possesses a greater density and a smaller coefficient of contraction than the liquid or solid but hotter matter beneath, by accretion and solidification from which the crust is gradually thickened, it is easy to see that such a relation may subsist between these quantities that the distance of the centre of gyration of the globe from its centre of figure may remain constant, either always or for very long periods, although the diameter of the earth as a whole may have diminished by contraction; and thus, since the moment of momentum must have remained unchanged, the angular velocity, upon which the length of the day depends, may have remained constant (or so nearly so that its variation may have been absolutely insensible) for 2000 years, or perhaps for a much longer period, notwithstanding that the world, as a whole, may have been losing heat all the time at a very sensible rate per annum, as seems to be the undeniable fact.

46. Let us take up the train of phenomena of refrigeration from the period when we may suppose the whole globe a liquid spheroid in fusion, rotating upon an axis inclined to its orbit as now, losing heat by radiation, and receiving that of the sun. Whatever the rate of refrigeration generally, it must have been *greatest* towards the poles; so that any solidified crust must have first formed about the poles and spread thence in two hemispherical sheets, getting thinner as they neared the equator, where they ultimately joined. From what we know by our mere furnace or laboratory experience of the effects of our highest temperatures on metals and on the materials that we must presume constitute the mass of our globe, it is certain that, at temperatures exceeding their fusing-points, they become more and more liquid up to some not yet known limit, and that at points a good deal above those of fusion they are all reduced to mobile liquids of extremely small viscosity.

47. On the other hand, it is equally certain that all metals, and such mixed materials as constitute rocks (acid and basic silicates), pass through a rapidly increasing phase of viscosity as they pass below the fusing-point on their way to ordinary solidity. It is this interval of rapidly increasing viscosity below the fusing-point and above that of complete solidification that enables platinum and iron &c. to be welded. This stage of viscosity in metals is very brief; but in earthy mixtures or compounds, such as the acid or basic silicates, it is much more prolonged, and the increase of viscosity towards the inferior limits of temperature much greater than in metals.

48. With the extreme fluidity of the molten spheroid at the exalted temperature that we must infer for it at the time of its first condensation from vapour, and after the first great chemical equilibrium of its elements (then entered into combinations analogous to those we now find in the globe so far as we know it), it is not conceivable but that

great currents of circulation must have arisen within the spheroid, by reason of the more rapid cooling at the poles than in equatorial regions, warmer currents proceeding superficially from the equator towards the poles, and colder currents returning about the axis of rotation, and dividing and ascending about the plane of the equator.

But the effect of these in equalizing the temperature of the superficial and deep parts of the spheroid would be small; it would, notwithstanding their influence, be always greatly hotter at the centre than at any part of the surface or near it. The exterior *couches* becoming more and more viscous as refrigeration proceeded, a *thin* solid crust would at length be formed over the whole spheroid, thickest at the poles.

This crust, while *thin*, though solid through a certain thickness, would be very nearly at the same high temperature as the viscous and the fluid matter beneath it. It would therefore still continue to part with heat by radiation at a rate not very far different from what the surface of the liquid spheroid did prior to formation of any crust.

49. But it is certain (as will be hereafter shown) that the coefficient of contraction per degree is less, for such materials as rocks are formed of, when in the solid than in the viscous or liquid state, and decreases as a function of the temperature down to the mean temperature of our present atmosphere.

It would depend upon the rate of surface-cooling, compared with that of the viscous matter below, and upon conditions of radiation &c., for which we have no sufficient data, whether the relations between the rate of cooling and of the contraction of the exterior and interior might not give rise to tensions within the *thin* crust; but upon the whole the effect would appear to be to produce tangential *pressures* also within the *thin* crust. To the compressions producible by these the thin crust would readily give way by wrinkling or folding over, or equally give way to tension by breaking to pieces. The density of the solidified matter in this thin crust was no doubt greater than that of the viscous layer beneath it, and the density of the last greater than that of the liquid matter still deeper; but the difference in density must have been small (as we shall hereafter see), the difference of temperature between such layers being so. Nor can we attribute any *great* difference in density to any abrupt molecular change in volume known to accompany the passage from the viscous to the solid state in the materials of rocks. [The differences in density observed in the passage of mineral compounds from the vitreous to the crystalline state, and *vice versâ*, are not great, and in those cases the cooling has been comparatively sudden. In the production of RÉAUMUR's porcelain, the change by slow heating is preceded by abrupt cooling as glass. In our crust there was not abrupt cooling.]

50. The thin crust, even if more or less dislocated, would therefore probably still remain upon the surface, sustained by the viscous bed beneath and that by the liquid spheroid, and would not piecemeal sink down into the latter.

But should we assume it to do so, there appears the utmost improbability in the supposition, which originated with POISSON, and seems to be adopted by THOMSON, that the solidified sheets broken from such thin crust and constantly renewed would sink to the centre of the liquid spheroid, and *remain* there still solid, and so gradually, of such fiery débris, build up a honeycombed but solid nucleus, with liquid matter above it and a solid crust above all. When we take into account the excessive relative thinness of the original solid crust, a very few miles, perhaps only a few fathoms, and the small volume of its mass in comparison with the enormous volume of the liquid nucleus, through which the fragments of crust have to descend some 4000 miles, together with the enormous excess in temperature of the liquid approaching nearer the centre, it seems impossible to arrive at any rational conclusion, except that such sunken sheets of solid crust must be reduced to liquid fusion again by heat conducted into them from the heated liquid, the local temperature of which would be increased by heat generated by their fall through the liquid a distance nearly equal the earth's radius before they ever reached the centre; and assuming that the laws of gravitation *within* a spheroid, and the density of the crust and relative rate of compression with depth of the crust and of the liquid, would ever permit them to reach that centre, POISSON'S hypothesis, which has been a stumbling-block in the way of more rational interpretation of these difficult questions of primæval geognosy, should, the writer submits, be set aside.

51. In cooling bodies, as the loss of heat in equal times is greater the greater the difference in temperature between the hotter and colder bodies, the rate of cooling of the globe, when its general temperature must have exceeded that of our hottest furnaces, and when, as we must presume, that of the celestial spaces was the same as now, must have been very rapid. The amount of contraction also (aided as the cooling rate was by the circulatory currents within the liquid before referred to) must have been proportionally rapid.

52. The viscous crust must be supposed greatly thicker than the solid sheet above it. The enormous amount of rapid contraction at this period was, in the writer's opinion, met by that deformation of the spheroid which hollowed out the ocean-bed to very much the general outlines that we now see, and so assigned the general forms to the continents.

This cannot be viewed at present as much more than a conjecture; still it is one not without support both from authority and from facts. It seems impossible to assign any other machinery or one adequate in force to a *soulèvement* or subsidence so vast, extending unbroken over such vast areas, and which should give to the sections of both land and ocean-bed their actual forms, which (without regard to mountain and valley) are but vast flat, raised-up plains, dipping more or less abruptly down to equally shallow, flat, saucer-like plains of ocean concavity. Lateral thrust or radial pressure at local centres seems here equally inapplicable. It is for the physical astronomer to investigate the causes of this very striking and obviously not chance-configuration of this deformation on the surface of our globe. [It should also be remarked that a certain order in the form of the land (coast-lines) and sea indicates that these are not the mere result of superficial actions, such as deposition, denudation, and local oscillations of level, but must be ascribed to forces which acted (along with these or before them) upon a vast if not universal scale, and at far greater depths beneath the existing surface.]

53. It is a remarkable fact that the western coasts of nearly all the great masses of land are the steepest, and that even without reference to littoral ranges of mountain, such as the Andes or those of the Malabar coast*.

Now this is just what we should expect if the ocean-bed were the result of the depression of the surface of the spheroid by the deformation supposed; for the matter in the crust that descended, having a velocity of rotation due to its higher radius (that prior to depression), would, in descending to the level of the ocean-bed, tend to fall (and by so much of the energy of its whole mass of matter to push) to the eastward of the true vertical, just as a weight let drop from a height falls to the eastward of the vertical. This effect would be greater as the deformation was more rapid, but would never disappear while it occupied some finite time. [The rapidity of elevation has at all times depended upon the rate of refrigeration; and the latter, whatever its actual rate at any given epoch, must have been greater as the temperature of the earth's surface was higher as compared with space. Thus, when the temperature of the surface was, let us suppose, 1500° Fahr., the annual rate of elevation of great mountain-chains may have been considerable.] If, on the contrary, the continents were *raised* up by some inconceivable force of elevation, no such phenomenon would present itself; and it seems impossible to see how this could have occurred without the production of vast cavities beneath.

54. These sudden contrary flexures at the junctions of the continents and sea-basins initiated lines of fracture and of weakness in the early crust, along which we find ranges of mountains and volcanic action now.

55. The ocean-bed deformation took place most probably long before the surface-temperature was such as to admit of its being filled with a permanent ocean water, though probably for a long period depositions of boiling water, at an enormously high boiling-point, took place locally and in basins here and there, beginning towards the poles, alternately boiling away and being redeposited, and being thus attended with torrential rains and with great surface-currents and deluges of hot water.

56. To the solvent power of these and to their violent carrying and denuding action and prodigious powers of breaking up the rocky mass of the primordial crust, by comparatively sudden heating, by the continued conduction from below (in antagonism with the sudden cooling locally), by precipitation of comparatively cold water from above, must be ascribed powers of comminution and alternate denudation and deposition such as later geologic time, much less historic time, presents us with nothing but the faintest resemblance of.

And to this early machinery may be ascribed the production, as by a mighty mill, of the vast mass of comminuted material which has formed the assumed azoic and yet more or less stratified rocks, or of others of like character that may have preceded them.

---

* Dana (American Journ. Sci. 1847) has, however, shown a different possible cause for the greater prevalent steepness of mountain-ranges on one of their flanks, viz. the greater intensity of the tangential pressure at the less steep flank, or smaller resistance of the materials of the opposite one. This, however, gives no solution of the very general fact of western flanks being the steepest.—March 1873.

57. At length the crust became further indurated, and with its viscous bed beneath greatly thickened and convection cut off by it, as well as its coefficient of contraction diminished, arrived at that state in which it was thick enough to *transmit* tangential stresses within its own sheet. When the balance of contraction in a given time between the crust and nucleus beneath was such (the latter still in great part liquid, contracting fastest because of its large coefficient of contraction) that the crust began to transmit compressive tangential strains within its thickness, these were of great energy and acted through great ranges. And now the crust, thick and stiff enough to transmit these strains through great distances, began to corrugate and double up upon itself, and thus to elevate the greater and lesser mountain-chains, many of these overthrown and again elevated, whose united volume, could we obtain it, would be in some degree a measure of the total contraction of the spheroid, from the epoch of the crust having become thick enough to transmit powerful tangential thrusts down to a comparatively late geological period; for whatever small changes in height may have occurred and are even now taking place (as in Sweden, &c.), no *great* elevations of mountain-ranges seem to have taken place in posttertiary or pleistocene periods.

58. In this state of thickness of the crust of the cooling globe, on principles already alluded to in treating of the nature of elevatory forces, the great elevation produced by transmitted tangential *thrusts* must have been acccompanied by large *induced* or *secondary* orthogonal *tensions*, or extensions due to *difference* of thrust, and thus by great fissurings and by most of the great phenomena of faults and dykes and crystalline-rock intrusions which we observe.

59. Lastly, as refrigeration still proceeded and the crust became far thicker and more rigid, approaching in both respects the state in which it most probably now exists, began that balance and play of forces the effects of which are now recognized as volcanic, with their attendant phenomena of earthquake, thermal springs, &c., and upon the precise mechanism of which we must now enter more largely.

This, which we may call the period of volcanic regimen of our globe, in comparison with the brief span of human history, appears at the first glance one of uniformity.

Yet it is one of decreasing energy, as has been the case with each of the epochs of refrigeration preceding it; they could not have been otherwise if resulting from the thermal energies of a cooling globe.

60. We thus recognize four great stages of the operation of refrigeration, each less in energy than the preceding, but all due to the one all-pervading motive cause, loss of heat.

1st. The formation and the deformation of a thin and flexible crust, and with it of the superficial parts of the viscous or liquid *couche* beneath, shaping out the land and sea boundaries.

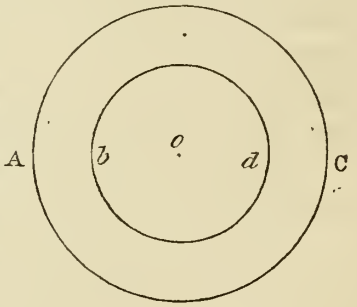
2nd. The splitting and breaking up of that crust and the more rapid (but irregular) cooling &c. produced by the first partial deposit of water upon the globe, while a large portion (of its surface even) may have been still red-hot, and communications partially open with the viscous interior; this accompanied by severe local tensions and compressions.

3rd. The increase of rigidity in the thickened crust, when it became able to transmit tangential thrusts due to contraction; and these (resolved as has been explained) elevated the mountain-ranges and originated the hypsometric configuration of the land, the establishment in regimen of the ocean and of the water-courses of the world, and with these the beginnings of climates fitted for successive forms of life.

4th. The epoch of a *greatly* thickened and stiffened crust with a comparatively slow rate of cooling of the globe, being the regimen which now exists, and of the play of the forces of contraction by cooling still going on, in and from which we now hope to show that volcanic action proper originated, and is preserved apparently uniform, though with a constantly decreasing energy.

These divisions in the progress of secular cooling are not merely arbitrary, for each is marked by a different way in which the effects of the contraction show themselves. The rate of contraction, enormous at first, because the rate of cooling was then most rapid and the coefficient of contraction the greatest, is met by deformation, afterwards by splitting up of the thin crust under tension (accompanied by welling up of the liquid matter from beneath), then, with a thicker crust, by folding over and elevation of ridges, primary tensions having given place to compressions, until at length the last and existing state of things is reached in which the crust has become of great thickness, and covers the still hot nucleus all over as a comparatively rigid spheroidal shell or dome; these stages more or less overlapped each other in their successive development.

Fig. 2.



61. How, then, is the contraction in volume of our globe which is now going on met? for if admitted to be cooling it must be still contracting.

We have a globe (A C) subject to the laws of gravitation, composed of a relatively thick crust, and enclosing a hotter nucleus, which is losing its heat by convection to the crust, through conduction and radiation from the surface.

The coefficient of contraction of the matter of the nucleus, which is at a temperature much higher than the crust, is greater than that of the material of the latter.

If the shell covering the nucleus were still thin and flexible it would give way, as formerly, by plication, and fall downwards by gravity as the diameter of the nucleus gradually diminishes by contraction. But the crust is now a thick rigid covering dome; its dimensions, owing to its existent small coefficient of contraction, are diminishing slowly as compared with those of the nucleus, whose coefficient, owing to its higher temperature, is much greater. Hence in fig. 2, taking the nucleus as $b\,d$, the thickness of the crust being $A\,o - d\,o$ (*i. e.* the integral thickness of all the crust, whether absolutely solid or solid enough to resist as an equilibrated dome), the more rapid contraction of the nucleus causes it to tend to shrink away from the interior surface of the crust-shell, and to leave the latter partially unsupported; or, if we assume adhesion between the two at the surface of contact, then the contracting nucleus as it shrinks tends to pull all parts of the spherical crust-shell along with it, radially towards the centre.

In either case the direct result is to produce mutual pressures by tangential strain in all parts of the crust-shell, which, as being sufficiently thick and rigid, resists these forces as a dome.

62. If the dome be incapable of resisting the tangential pressures thus produced, it must crush by the mutual compression of its parts; and if not everywhere homogeneous, or if the pressure be greater in some places than in others, it will crush partially along the weakest places or those most strained.

But as the material of the rigid dome or shell is, like all other matter, compressible as well as amenable to shearing-strain, so these tangential pressures must be attended with compressions, and therefore with *motion* in the particles of the material.

63. The "work" produced by these mutual pressures and motion is transformed into *heat*, which either heats the whole spherical shell uniformly, if the compressions or work be uniformly diffused through its volume, or heats certain points or lines or planes within it more intensely if the work due to intervening volumes be more or less transferred to those places. Let us fix this in the mind by an illustration.

Suppose we have an egg with its hard covering shell and softer interior, and that by some means we could cause the soft interior to diminish uniformly in volume so as to shrink away (or tend to do so) from the interior of the shell, and thus to leave the latter exposed to the pressure of the atmosphere. As soon as this takes place tangential pressures are produced within the shell, so that (if we imagine it a form of equilibrium) its particles mutually approach each other. The temperature of the whole shell will therefore necessarily rise, by the internal work thus produced; and, for illustration, we may suppose the increase of temperature the same in all parts of the shell.

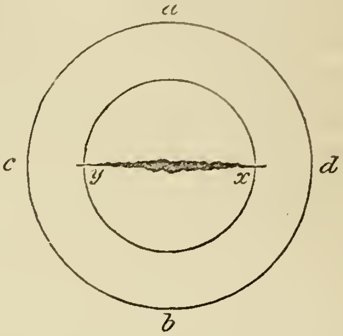
But let us now assume that the shell had been previously cracked through, along various irregular lines upon its surface (as we see eggs in boiling often are), or had like lines of weakness in it. As the compression will be greatest along those lines where the resistance to it is least, so the chief amount of the work of compression will be transferred to those lines of fracture or of weakness, and the increase of temperature produced by the greater part of the internal work will cause the parts of the shell about these places to become much hotter than the intervening parts of the unbroken shell. What the pressure of the atmosphere upon the unsupported egg-shell here does, is done by gravitation of the crust-shell itself, and attraction of the nucleus in the case of our globe.

64. Another and nearer illustration, indeed an almost parallel case, is presented by the phenomena that actually attend the cooling of large spherical or cylindrical masses of iron. A moderately sized sphere of *cast* iron which has been cast in an iron mould so

that the exterior becomes rapidly cooled to a rigid state, leaves a central cavity when cold, the last consolidating particles having parted company towards the centre under the constraint of the rigid shell, whose diameter does not diminish so as to accommodate the total contraction.

All very large cylindrical forgings of wrought iron, say of 2 or 3 feet diameter, become "flawed" as they cool, tearing asunder in greater or less irregular diametral and axial planes, as in section, fig. 3. The whole mass was at first, say, at a yellow heat and plastic; the outer coats cool first and most rapidly, and form a rigid arch (whose thickness we may suppose $\frac{cd-xy}{2}$) covering the still hot interior, and whose dimensions are determined by the volume of the latter which is grasped by the rigid arched shell. The cooling of the interior proceeds, the heat being lost through the rigid shell; and as the shell cannot yield to the radial pull of the contracting nucleus $y\,x$, the diminution in volume of the nucleus is met by its tearing asunder in some one diameter, $y\,x$, and by deformation of the cylinder itself in the orthogonal direction as soon as this rent has been formed.

Fig. 3.



The exact play and interdependence of these forces, here imperfectly stated, have been fully developed by the writer in a paper "On the Coefficients of Elasticity and of Rupture of Wrought Iron, &c.," printed in the 18th volume of the Minutes of Proceedings of the Institution of Civil Engineers, pp. 307–312, to which he would refer. The case of a cylinder is (as regards illustration) the same as a sphere, as the material of the nucleus is there too viscid to escape endways.

65. In the case of a *small* cylinder or sphere with a relatively very thick and rigid shell, the final contraction of the nucleus is met, as we see, by tearing asunder of the nucleus by radial tension, and not by crushing of the material of the covering dome by tangential compression.

But it is obvious that the one or the other must result, as the sum of the tensile resistances of the nucleus or that of the compressive resistance of the covering dome is the greater.

And in a very *large* globe such as ours, where the active force is gravitative in all its parts, and where transverse section in the plane of any great circle enormously exceeds that of the shell, even if we suppose that some hundreds of miles in thickness, it is obvious that it is the shell that must yield by crushing up, and not the still heated nucleus by pulling asunder, though it is quite possible that in some remote future stage of final refrigeration a diametral rent might occur, or some central cavity be left in the *then* cold and rigid nucleus itself of our globe.

66. The contraction *now* going on in our globe by its secular refrigeration is met therefore by the compression of the colder and more rigid covering shell and crust, and by the crushing of its material along lines or at places or planes of weakness by their mutual

pressures, produced by the gravitating of the shell itself towards the contracting and attracting nucleus beneath it.

The work thus developed is transformed into heat; that heat is greatest along those lines or planes or places where the movement and pressure together constituting the work are greatest. Along or about such places of concentrated compressive and crushing work the temperature may locally rise to a red heat, or even to that of fusion of the rocky materials crushed, and of the pressing together walls themselves adjacent to them. This, then, is the writer's view of the real nature and origin of volcanic heat as now produced in our globe; it comes not from a free communication with a primordially and still fluid interior ocean, nor from such communication with isolated lakes of liquid rock, which have no probable existence, but is *produced* below the places where it appears in volcanic vents, or beneath and adjacent to them, by the mechanical energy of the compressed-together shell, as that falls down by gravity upon the contracting nucleus; and the heat so *produced locally* is again *consumed locally* and disposed of by the origination of chemical work and by reconversion into mechanical work, chiefly of ejection.

And thus though volcanic energy as we see it on our globe is *not the direct* product of primordial heat of fusion, it is indirectly due to the loss of that heat, being simply one result of the cooling of our globe and of the acknowledged laws of gravitation.

Volcanic energy (or vulcanicity in general, as comprehending in it earthquakes and other of the so-called plutonic phenomena of geologists) may therefore be defined, according to the writer's view, as follows:—

Definition.

67. *The heat from which terrestrial volcanic energy is at present derived is produced locally within the solid shell of our globe by transformation of the mechanical work of compression or of crushing of portions of that shell, which compressions and crushings are themselves produced by the more rapid contraction, by cooling, of the hotter material of the nucleus beneath that shell, and the consequent more or less free descent of the shell by gravitation, the vertical work of which is resolved into tangential pressures and motion within the thickness of the shell**.

68. It has been pointed out that in the earlier stage of secular cooling, when the immense contraction was met by *deformation* of the exterior portions at least of the spheroid, great lines of weakness through sharp curved bendings and fractures were produced. All subsequent action has tended to increase the number and extent of these; and it will pro-

---

* [The production of heat as a consequence of the condensation of gases or vapours in progress towards liquefaction or solidification has been noticed by Mr. Herbert Spencer in his "Essay on the Nebular Hypothesis" (Westminster Review, July 1858). It need scarcely be remarked that this is altogether different from the source of volcanic heat here pointed out, nor has the writer's view been in any way anticipated by Mr. Spencer.]

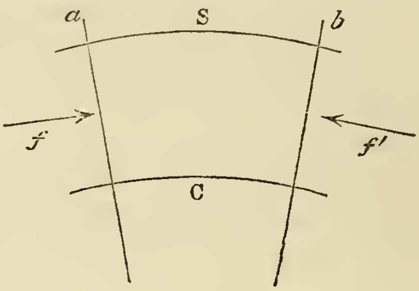
bably not be denied by geologists that every thing we know of points to the existence of great sweeping lines of weakness and of broken continuity in the crust of our globe, as, for instance, round the shores of the Pacific Ocean. Beneath and adjacent to such lines we must suppose the rocky materials fractured and broken up, and over large areas and to great depths reduced to discontinuous fragments closely pressed together and gripped in contact.

It is just along and over such places that we find volcanic vents. Along such planes of weakness, extending to great but unknown depths, the temperature should be highest by the concentration thereabouts of the movements of the compressed crust, as already shown.

69. But such heated areas are not confined to merely vertical planes, at least for so far in depth of the entire solid crust as consists of superposed and interposed formations differing in mineral character, or (what we are here alone concerned with) in compressibility and conductivity, one or both.

70. In fig. 4, if S C represent the depth of the earth's crust, a portion of which of unit thickness is comprised between the vertical planes *a* and *b*, and submitted to compression by the opposite tangential forces *f* and *f'*, then if the entire mass in depth between C and S be of homogeneous material of uniform compressibility, any rise of temperature produced by compression will be uniform throughout its mass.

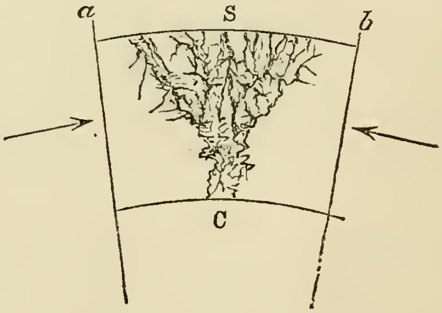
Fig. 4.



But if the compressibility be *less*, say towards C, than higher up, then, supposing an adequate force acting equally upon all points of the planes *f* and *f'*, and that the *more* compressible material is not reachable by the pressures until after the less compressible material shall have given way, the temperature will not be uniform, but will be greatest where the work of compression is so, and thus we should have variations of temperature with depth in any gradual order, whether ascending or descending.

71. This will also, though in a less regular way, be true if, as in fig. 5, the mass *a* C *b* include a great plane of weakness, due to fracture &c., extending in depth in a variable way. Thus if the material be more compacted towards C than higher up, and so less compressible, and if, as before, the tangential pressures *f* and *f'* act uniformly upon the vertical planes *a* and *b*, so that they can only approach each other at the rate the less compressible matter about C gives away, then must the highest temperature be developed about C, where there is the largest amount of work.

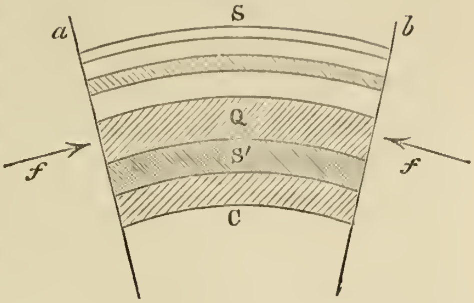
Fig. 5.



72. Thirdly, let us suppose the mass *a* C *b* to consist of several beds or layers of various

compressibilities and submitted to the forces f and f' as before; and, further, suppose that, for example, the bed Q (fig. 6) is less compressible than at S′ just below it, or than other beds in the series. Then, under the conditions, as the work of compression is greatest in the bed Q, that bed will, if its compressibility be everywhere alike, be uniformly hotter than the adjacent beds.

Fig. 6.



There will here be not a vertical or nearly vertical plane or plate of increased temperature, but a horizontal one.

73. The greatest amount of *work* may not be always in the least compressible rock; for as work is the product of pressure and *motion*, a soft easily yielding rock with a *large range* of compressibility may, by the application of a given amount of pressure, produce the greater amount of work.

74. The extent to which a bed of rock may thus be heated by compression *without any crushing*, i. e. by pressure far within its elastic limits, may be illustrated by an example. In the writer's own experiments on the compressibility of the rocks at Holyhead (Appendix to Account of the Earthquake Wave-Experiments made there, Phil. Trans. 1862, vol. clii. pp. 663–676), he found that certain quartz rocks and certain slate rocks both bore about 12,000 lbs. per square inch before their elastic limits were passed, the total compression at this pressure being 0·13248 for the quartz and only 0·04464 for the slate upon the unit length. The foot-pounds of work in compressing each to this amount (from which the rock would recover when released), divided by J (Joule's equivalent), shows that a prism of a foot square and 100 feet long of each rock would develop the following British units of heat:—

Quartz = 295·200.
Slate = 100·800.

If consisting of these rocks, therefore, and both compressed by precisely the same force, 12,000 lbs. per square inch, the bed Q (fig. 6) of quartz would be nearly three times as hot as that, S′, of slate beneath it, and the former would communicate its heat to the beds both above and below.

75. In this we see, then, one very sufficient cause for great inequalities in the rate of increments of hypogeal temperature, which, so far as the writer knows, has escaped notice, and which did not occur to Mr. Hopkins when (see his paper, Phil. Trans. vol. cxlvii., 1857, alluded to in a previous part of this paper) he discovered that central heat and difference of conductivity alone were not sufficient to account for the phenomena of increase of heat with depth. Indeed, as we shall see before concluding, the perturbations of the hypogeal temperature arising thus from intestine pressures and motions within the earth's solid shell *must* be far greater than has hitherto been suspected, and may amount to a very large fraction of the heat received from the nucleus.

The heat thus produced by such intestine work is, so to say, actually generated within that shell, and in amount is dependent not so much on how much is received from below as on the amount of *contraction* of the material of the nucleus, which is, of course, a function of its total loss of heat in all ways. As the heat thus developed unequally by compression at different depths may vary, we at once obtain an explanation of what has been observed at Dukenfield shaft and elsewhere (namely, discontinuity in the series of heat increment), and perceive how a warmer or a colder *couche* may be interpolated. In fact we have a real source of perturbation distinct from difference of conductivity and presence of percolated water, which alone engaged Mr. HOPKINS's attention.

76. But the evolution of heat within the solid shell by the variable compressibility of the superposed formations thereof does not end with the compressions of the material of each or all the beds.

Any two superposed beds, such as Q and S′ in fig. 6, exposed to the same compressing force, as they have unequal coefficients of compressibility, *must slide upon each other*, and so produce frictional and disintegrative work between the sliding surfaces; this also becomes transformed into heat, and further tends to raise their own temperature and those of adjacent beds.

77. Lastly, we must take into account that the tangential forces cannot be always, as we have assumed in $f\ f'$ (figs. 4, 5, 6), uniform at all depths; for independent of any general law connecting the gravitation of the shell with those tangential forces (to which we shall presently refer), the mere inequality of resistance at various depths, which we have shown, must derange that equality of pressure, and even within certain limits change its direction locally from being strictly tangential into directions more or less oblique, both vertically and horizontally.

Although we *know* nothing of the constitution or order of the materials constituting even the solid shell of the globe deeper anywhere than perhaps 70 miles at most (inferentially), and to perhaps 25 miles by observation and inference, still the discussions of DUROCHER and others warrant our assuming it, to a far greater depth than above, as not differing greatly from the harder crystalline rocks of the surface, and indicate that below the stratified deposits, say below 25 miles or so in depth, the material may be presumed, with high probability, to be much more uniform, less shattered, and denser than near the surface.

78. If we have thus discovered a true and a sufficient cause for great local elevation of temperature within the solid crust of our globe, it is submitted that we have really discovered the origin and nature of volcanic action, and proved it to be only part of the acknowledged cosmical machinery of our globe, independently of any question as to how hot it was originally, or what length of time may have since elapsed, or what may be its internal temperature now (save that the interior of the globe is still hotter than the exterior, and that the whole is cooling), or whether the nucleus be liquid or solid, or the shell be thicker or thinner.

For, a sufficient source for the high local temperature at *some* depth below volcanic vents being discovered, the presence at their *foci* of water, fresh or salt, completes the whole machinery by which these huge heat-engines work; and with the two together, all their ascertained phenomena as to ejecta and other products admit of easy explanation.

We shall recur to these and compare the chief of these phenomena and of plutonic action generally with our cause for the local production of the heat itself, though necessarily briefly. For volcanic phenomena such as have always been known to us in historic time or by traces left before that, and which are characterized by a general uniformity of products and mode of action all over the globe, as well as in all time, differing only or mainly in intensity merely, the necessary *coexistence* of some source of high local temperature and of water to form steam is required. It is obvious, therefore, that no such volcanic action as we are now acquainted with can have existed on our globe prior to the deposition upon it of the great masses of superficial waters penetrating its solid materials by capillarity and infiltration to vast depths—that is to say, not until after the external surface of the globe had permanently fallen to the temperature at which liquid water could deposit and penetrate the earth's crust; and this fixes an anterior limit in time earlier than which vulcanicity, as we now know it, cannot have existed upon our globe.

79. We have no very precise data for fixing this commencement of existing volcanic action in the geologic scale of succession, but it probably does not go back much beyond the end of the Secondary period, if so far. Prior to that vulcanicity seems chiefly to have been developed in the welling up of huge volumes of liquid rock between severed masses, or masses of heated dust or so-called ash, and probably in other ways, but without ejecta due to elastic steam, though possibly to such occasionally due to gases, but in any case to have been different in its action from the present system, and to have formed but a part of the machinery of folding over and ridge elevation of the earlier stages of cooling and contraction.

[It is not impossible that volcanic vents, or other sufficient evidences of true volcanic action of the explosive character now in play, may hereafter be discovered in the older sedimentary formations. The so-called deposits of "volcanic ash," the trap-dykes and porphyry-bosses of the Silurian rocks of the south of Ireland and of North Wales, &c., are evidences of igneous action indeed, but of that hydrostatic character which preceded the explosive volcanic action of the present epoch.

Some of the phenomena of explosive action are occasionally observable in igneous formations undoubtedly not volcanic, as the greenstone or trap-boulders and pebbles found by the writer imbedded in the great greenstone or trap-dyke of Galway (Trans. Roy. Irish Acad., 1834); but no sufficient evidence exists, so far as his knowledge goes, of any volcano, properly so called, existing in Silurian times, nor for long after. Nor, if the existence sporadically of such were proved, would that controvert the writer's view, that the great system of explosive volcanic vents as now established on our globe does not date back *in the main* further than above stated. No precise boundary in time can be assigned for the passage from the hydrostatic to the explosive system. The change was gradual; and just as the epochs of land and sea forming by deformation overlapped that of mountain building by crumpling, and that again has overlapped in time our existing epoch of volcanic crushing and explosive action, so did the great epoch of hydrostatic igneous action overlap more or less the commencement of the existing volcanic era. The more ancient form of igneous action, by which the enormous trap protrusions &c. were poured forth upon a scale, as lately observed in California, wholly inconsistent with existing volcanic forces, continued in force down to comparatively recent periods, as of the Chalk, and may even yet be going on possibly under the sea. But two main characteristic facts remain—namely, that the most ancient igneous workings were hydrostatic and not explosive, while the existing or volcanic activity (properly so called) is explosive and is not hydrostatic; and, secondly, that upon the whole this last or existing form of igneous action (the explosive) does not, when viewed largely, date back further than to some part of the Secondary period, and that a preponderant amount of it is of still more recent date.]

80. It follows, therefore, that a like machinery of volcanic action to that now existing in our globe cannot have existed in any other planet anterior to its surface having assumed such thermometric conditions as enabled water or some equivalent fluid to become permanent upon its surface. That temperature might be very different from ours as now existing, and was once no doubt far above 212° upon our globe.

But it does *not* follow (as has, indeed, already been suggested) that in a planet or satellite constituted very differently from our globe volcanic action may not be maintained, for a longer or shorter time, by chemical actions, or by these and mechanical ones together, of a far different nature from the vulcanicity seen upon our globe—such as the evolution of gases from liquid or solid matter at one temperature and their absorption at others, as in the case of melted silver and copper absorbing oxygen, or of the numerous cases of such chemical actions in compounds discovered by TESSIE DU MOTAY, or in many other imaginable ways.

81. The writer is now called upon to show that, assuming the origin for the heat thus produced, which is the moving energy of the volcano, the conditions are such as to prove it to follow from forces real and adequate to the result.

He proceeds to do so, and for this it is necessary to show:—

1st. That the gravitation of the unsupported or but partially supported solid shell is adequate to crush into powder all the materials of which it consists, and that no matter how thick the shell may be unless equal to the whole radius.

2nd. What is the total amount of contraction of materials analogous to the rocks of the solid shell, between their temperature of fusion or one above it and that of our atmosphere now.

3rd. What is the mean work per unit of weight and volume necessarily expended in crushing to powder the rocks of which the solid shell consists, and what is the amount of heat due to the transformation of such work.

Lastly, we have to compare these results and apply them to the actual phenomena of volcanic action on our globe.

The first of these involves a mathematical investigation only, the last two rest upon two extensive series of experiments which have been made by the writer and are here to be detailed.

82. First, then, the unsupported solid shell must crush by its own gravitation and that of the nucleus, if of any solid material known as part of our globe.

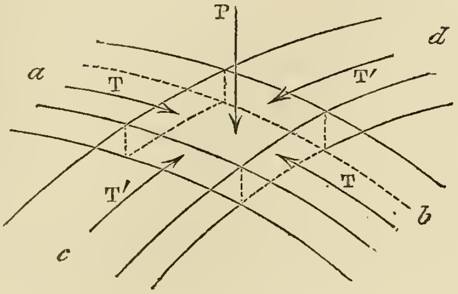
Lagrange, in his 'Traité de Mécanique Analytique,' cap. iii. sec. ii. (statique), "Sur l'équilibre d'une surface flexible," &c. (Bertrand's 4to edition, Paris, 1853), has given, though in an involved form and without proof, a theorem which is applicable to this question. This theorem has been reduced to simpler form by Professor S. Haughton, F.T.C.D.*, who has applied it to a widely different subject from ours, and to whom the writer is indebted for having had his attention directed to its applicability to the present one.

A proof of the theorem has been since produced by Professor R. S. Ball, of Dublin (Phil. Mag. vol. xxxix. pp. 107 & 108, Feb. 1870). The theorem may be thus stated:—

If a curved surface (of the nature of a hollow shell or membrane) be in equilibrium when exposed to forces acting normally to the surface everywhere, then the normal pressure at any point is equal to the force in the direction of the surface (or shell) at that point, multiplied into the sum of the reciprocals of the principal radii of curvature.

The pressure may be internal (as in a blown bubble), producing tensions, or may be external (as in the case before us), producing pressures or thrusts in the direction of the surface or tangential to it; and the surface may be extensible or inextensible, but it is one into the consideration of which cross or shearing strains do not enter.

Fig. 7.



83. Let P (fig. 7) be the normal pressure upon a unit of surface (square inch or mile) cut from a pair of intersecting ribbons of the curved surface, as *a b* and *c d*, at right angles to each other and of unit breadth, T the tangential thrust on any of the faces of the unit square respectively opposite (which, as being small in relation to the radii of curvature, may be considered as plane).

Let the two radii of principal curvature (in *ab* and *c d*) be ϱ_1 and ϱ_2, then, as expressed in the theorem,

$$P=T\left(\frac{1}{\varrho_1}+\frac{1}{\varrho_2}\right), \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad \text{I.}$$

T′ having the same value.

As regards the present application of the theorem, as the differences of ϱ_1 and ϱ_2 for our globe are very small (comparable with the difference between the polar and equatorial radii) and scarcely sensibly affect the curvature of the surface within limited areas, we may consider our globe as spherical and $\varrho_1=\varrho_2$, whence equation I. becomes

---

* And by Professor Miller in his 'Hydrostatics' (Cambridge, 1831).

$$P=\frac{2T}{\varrho}, \quad \ldots \ldots \ldots \ldots \quad \text{II.}$$

and

$$T=P\times\frac{\varrho}{2}. \quad \ldots \ldots \ldots \ldots \quad \text{III.}$$

If the curved surface be very largely elliptical, then the value of T given by this equation is not quite exact, as may happen in cases of local elevation or depression from local causes; but we are not here concerned with this further, as we shall view the globe as spherical without sensible error.

Now, to apply this to our case, let us suppose that we have a spherical shell of only one mile thick forming the surface of our globe, that it preserves its form by equilibrium, and that it is *wholly* unsupported by the nucleus below it, by the attraction of which, resulting in its own weight, it is urged towards the centre of the sphere.

84. Let the shell be of the most resistant rocky material which we know of, viz. granite or porphyry, crushing at 14 tons per square inch, or a little above 2000 tons per square foot, and of specific gravity=2·858, or weighing from 175 to 180 lbs. per cubic foot. Our results, which only require, as for illustration here, to be approximate, will not be materially affected by our assuming the diameter of the globe 8000 miles each of 6000 feet or 1000 fathoms, which will save a mass of figures. The result will be quite comparable with those we should obtain by taking the sphere at 7920 British statute miles. Now in equation III.

$$T=\frac{P\varrho}{2},$$

$\varrho=R$, the radius above taken for our globe, and therefore

$$T=2000\,P;$$

but in the case of the shell of 1 mile thickness, P=the weight in tons of 1 cubic mile of its material, *i. e.* of granite or porphyry, which, as a cubic fathom of water weighs very nearly 6 tons, will be $6\times2{\cdot}858$ tons per cubic fathom, or $1000^3\times6\times2{\cdot}858$ tons per cubic mile. Then $T=2000\times1000^3\times6\times2{\cdot}858$ tons, the horizontal thrust per square mile, which, divided by the number of square feet in a square mile, viz. $1000^2\times36$, gives as the value of T for the square foot

$$T=952666 \text{ tons},$$

which is more than 472 times greater than the crushing load given for granite or porphyry.

This simple investigation will sufficiently apply to any cubic mile in a like covering shell, even if 100 miles (or even more) in thickness, the variation in the force of gravity at that depth, $\frac{1}{40}$ of the assumed radius of the globe, being so small that we may here neglect it.

The subject may be viewed more intelligibly perhaps in the following way. As T is proportionate to $\frac{P}{2}$, whatever value we take for R, a cubic mile of rock in any portion of the self-sustaining shell is exposed to a horizontal thrust upon each of its vertical faces $=\frac{R}{2}$ times its own weight.

That on our previous data will be 2000 times its own weight; but on the same data the crushing load for granite or porphyry being about 2000 tons per square foot, and the weight of the material 178 lbs. per cube foot, the modulus of cohesion, or the length of the column in feet of the material that shall crush by its own weight, is $\frac{2000\times 2240}{178}=25169$ feet$=4{\cdot}195$ miles of 6000 feet. But the height of the column of the same material representing the horizontal thrust is 2000 miles, or nearly 480 times the height of the crushing column.

In fact while the materials of the hardest and most coherent rock are crushed at 14 tons per square inch, the crushing force is here upwards of 6000 tons per square inch, if the equilibrated shell be, as assumed, wholly unsupported. It follows, therefore, that if $\frac{427}{428}$ of its total weight from attraction by the nucleus were supported by the latter, or that it were only free to descend by $\frac{1}{428}$ of the total gravitation, the materials of the shell must still crush.

85. If the thickness of such a terrestrial shell be considerable (as supposed by Mr. HOPKINS), the question arises at what depth from the outer surface will the *couche* of maximum tangential pressure be found.

[Let T and P be the horizontal thrust and the pressure, T as well as P being now referred to a unit of surface, and W the weight of a unit of volume, estimated at the depth at which it is situated, not as brought up to the surface of the globe, the equation for vertical forces in a sectorial element is

$$2\int_r^R \mathrm{T}r\,dr+\mathrm{P}r^2=\int_r^R \mathrm{W}r^2dr,$$

R being the radius of the globe, and r the radius vector from the centre drawn through the unit volume; whence

$$2\mathrm{T}r-\frac{d\,.\,r^2\mathrm{P}}{dr}=\mathrm{W}r^2,$$

the condition of equilibrium between T and P.

Two extreme suppositions as to the *physical* state of the globe (or its sectorial element) present themselves:—1st, that it consists of successive thin dome-like *couches* superposed, each rigid and self-supporting, so as to transmit no pressure to those below; or, 2nd, that no dome-like support exists, but that each *couche* transmits pressure to those beneath, as in the case of a liquid.

On the first supposition

$$\mathrm{P}=0 \text{ and } \mathrm{T}=\tfrac{1}{2}\mathrm{W}r;$$

on the second supposition P=T and

$$\frac{dP}{dr}=-W \text{ and } T=\int_r^R W dr.$$

If ϱ (a function of r) be the density, g being the force of gravity at the surface, then gravity at the depth r is

$$\frac{\frac{1}{r^2}\int_0^r \varrho r^2 dr}{\frac{1}{R^2}\int_0^R \varrho r^2 dr}g=\frac{R^2}{r^2}\frac{\int_0^r \varrho r^2 dr}{\int_0^R \varrho r^2 dr}g,$$

and

$$W=\frac{R^2}{r^2}\left(\frac{\int_0^r \varrho r^2 dr}{\int_0^R \varrho r^2 dr}g\right)\varrho.$$

Thus, for example, let ϱ be constant as to depth, then

$$W=g\varrho\frac{r}{R}.$$

Upon our first supposition

$$T=\tfrac{1}{2}gr\frac{r^2}{R},$$

and upon the second

$$T=\tfrac{1}{2}g\varrho\left(R-\frac{r^2}{R}\right).$$

In the first case $T=\frac{1}{2}g\varrho R$ at the surface of the globe, decreases with increasing depth, and becomes zero at the centre. In the second case $T=0$ at the surface and equals $\frac{1}{2}g\varrho R$ at the centre.

For the above expressions I am indebted to Professor STOKES, Sec. R.S.]

86. Mathematical considerations only would thus indicate that in a thick terrestrial crust, assumed rigid and composed of dome-shaped laminæ of superposed rock all of equal density and cohesion, the horizontal thrusts tending to produce crushing will be a maximum at the superior surface and a minimum at the inferior surface; but that if composed of loose discontinuous material, or of any material such, in relation to the vast volume of the crust and to the immense forces engaged, that it can transmit interior pressures in all directions, as a quasi liquid or plastic body, the maximum deforming thrusts will be greatest at the inferior surface and nothing at the superior surface.

87. So far mathematical investigation serves us; but it throws but little further light upon the question that most interests us here—namely, at what fraction of the entire depth of such a thick terrestrial crust will be found the *couche* of maximum vulcanicity, that is to say, of greatest work in crushing or deformation. This depends not only on the depth at which T is a maximum, but on that at which the *couche* of maximum resistance to T is to be found; and this latter depends upon the nature of the materials at all depths, as well as upon their state as forming the shell of a globe such as ours. Viewed upon the great scale, our earth's crust is neither quite rigid and dome-like nor

yet quite plastic, like a viscous liquid, to the movements of which, however, it may much approximate. The superior surface is the most rigid as to conditions due to temperature, but it is for miles in depth shattered, heterogeneous, and more or less discontinuous; the *resistance*, therefore, at the surface is smaller than at some considerable depth beneath.

Again, as we must suppose (to accord with almost any conception we can form of the change produced by hypogeal heat) that the lower surface of the shell is softer and more viscous than its upper surface, inasmuch as at the former it passes into a much hotter and probably liquid nucleus below it, so the thrust T (whatever its effect may be to *squeeze* and distort a more or less compressible viscous mass at the lower surface of the shell and just below it) must produce its greatest mechanical effect in dislocation and *crushing* at some point above. The mere *squeeze* of a viscous mass, producing compression or distortion or both, must produce transformation of work into heat, and so may reduce to a fused liquid state matter before viscous only; and in so far as this can act in the way of cause, volcanic activity must not be excluded from the local compressive actions, paramount amongst which is their effect in crushing, as being all manifestations of the tangential pressures within the crust to which volcanic action is here ascribed.

88. [It will be lower down from the earth's surface as the uppermost formations are less resistant, and higher above the lower surface where the materials pass from the solid to the liquid condition as the depth occupied by viscous matter is greater. It will also vary with the depth, in so far as the coefficients of density, ridigity, and ultimate cohesion are themselves affected by depth and pressure.

With a given thickness of solid shell the problem of the depth at which the volcanic *couche* should be found is at present, therefore, not determinable, though we may make many more or less probable hypotheses as to the constitution of the crust, from which probable depths for it may be inferred—as, for instance, if we assume a certain depth below the surface at which the material is homogeneous and unshattered, and that the coefficient of viscosity decreases according to some assigned law from a liquid inferior surface until we ascend to the above level.]

In these considerations (which the writer is quite conscious are very far from forming a mathematical investigation of an exact character, or embracing any thing like the whole of the complicated relations that are presented in nature) it is assumed that each spherical element of the entire thickness of the shell supports itself, and that the value of P is not largely affected by the diminution of the force of gravity in descending, no attempt being made to follow out the complex conditions that may arise when the crushing has taken place in various conceivable ways.

89. The writer's immediate object here is limited to proving that the resolved forces of gravitation are sufficient to produce crushing of the solid terrestrial shell, whether that be thick or thin, if left partially unsupported by the shrinking away of a cooling and contracting nucleus from beneath it; and this he believes he has now done.

90. He may be permitted, in corroboration of the general truth of what has been just advanced, to refer to an extremely able memoir (which scarcely, if at all, seems to be known to the physical geologists of Great Britain) by Signor Prof. GIUSEPPE BELLI, of the University of Pavia, entitled "Pensieri sulla consistenza ecc. della crosta solida terrestre," published in vol. ii. New Series, of the 4to Journals of the Institute of Lombardy, in 1850. In note 1 to p. 6 of the memoir, pp. 3–14, entitled "Sulla resistenza della crosta terrestre alla compressione," Prof. BELLI has given a long and able investigation of very much the same question as we have here considered, and arrived at results completely confirmatory, though by an entirely different path of investigation.

He assumes, on certain grounds, the solid shell to be rather more than 30 Italian geographical miles (60,000 metres) in thickness, that it is subject to its own weight, its density being taken at 2·5 to 3·0 as compared to water, arising from the attraction of the nucleus, whose density he takes at about 5·6, which he further supposes, though in contact with the interior of the shell, to offer no resistance to the descent of the latter through a very small distance; *i. e.* he supposes, as has been done here, the nucleus to shrink away by cooling from the crust above it.

Supposing the whole globe cut by a plane passing through the equator, he investigates the pressure by which gravitation will urge the annular surfaces of the two opposed hemispheres against each other, and arrives at the conclusion that it would be equal to the pressure of a tower (*torre*) or hollow cylinder of material equal in density to the crust and standing upon the annular surface of 30 miles' width, of 1716 Italian geographical miles in height—that is to say, in height equal to about half the radius of the earth.

Whence he shows that no known material could sustain such a strain; that were the crust of cast iron it could only support $\frac{1}{180}$ of the crushing force to which the gravitation of the whole system exposes it, if of porphyry $\frac{1}{350}$, if of wrought iron $\frac{1}{619}$, if of granite $\frac{1}{1077}$, and if of (*marmor*) primary limestone $\frac{1}{2590}$ of the whole.

He concludes, therefore, that the solid shell does not support itself as an equilibrated dome, but that, in fact, it is almost wholly supported by the fluid nucleus upon which it floats; and he then attempts to show that the rising of lava in volcanic vents is a consequence of the partial or unequal sinking of the discontinuous fragments of the shell into the liquid of the nucleus. It is to be regretted that BELLI, after having made so good a commencement, should have been misled by his supposition of a very thin crust and a liquid nucleus into an entirely wrong track, and so come to adopt a view of the mechanism of volcanic action often proposed before him, and which the writer believes to be untenable. It may be desirable to show, however, that by LAGRANGE's method we can treat the question of the crushing of the crust from the same point of view as BELLI has done, and arrive at substantially a like result.

We have shown that, for the unit of length of a section of the shell,

$$T=\tfrac{1}{2}PR;$$

therefore, for the entire equatorial annulus or section of the shell,

$$T_0=2\pi R\times\frac{R}{2}\times P,$$

or

$$T_0=\pi R^2\times P;$$

but as P is the weight of the cubic unit of the shell, W, the weight of the hemispherical shell, is

$$W=2\pi R^2\times P;$$

hence

$$P=\frac{W}{2};$$

that is to say, the mutual pressure by gravitation (under the condition of shell and nucleus) of two hemispheric shells taken in an equatorial plane is equal to one half the weight of one hemisphere.

91. Signor Belli enters into several subordinate discussions as to the probable modifications of resistance to crushing that may arise in rigid materials when exposed to great compression in all directions, and whether the tendency to crushing will be increased or diminished by the simultaneous action of two orthogonal pressures. These refinements are not required for our purpose, as we may conclude that no modification of condition of application can enable a rigid solid to remain coherent under pressures *several hundred* times greater than will crush between two opposite surfaces a cube of the same material.

92. The cube in this case is exposed to pressures on two faces, and is free to yield in four directions at right angles to the pressure and opposite to each other respectively; but a cube such as the unit-cube of our shell, exposed to pressures simultaneously on four of its faces, is only free to yield in two directions parallel to each other and at right angles to the pressures. Direct experiments on this point have not, to the writer's knowledge, ever been made; but certain facts well known to engineers appear to warrant the conclusion that rigid bodies, such as cast or wrought iron, steel, or bronze, are weakened (*i. e.* the tendency to become broken up is increased) by the simultaneous application of orthogonal pressures or tensions.

93. Thus, for example, the metal of the interior of a discharged cannon is exposed at any point at once to compression radially to the bore and to two orthogonal tensions, longitudinal and circumferential, and it is known that the resistance of the material thus is less per unit of section than of the same exposed to tension or compression in a single direction only.

94. Another question may arise. If the earth's solid shell be of very considerable thickness (as it almost certainly is), and if we conceive a cubic unit of it at a large depth exposed necessarily to pressures upon all its sides, how is the cube to suffer such deformation as shall admit of crushing at all?

The pressures on the two pairs of opposite and vertical faces are equal and opposite T and T_1.

The lower face of the cube *may* be free more or less to descend, by further compression of the material far below, whether solid, plastic, or liquid, but the uppermost face of the cube is free to ascend by merely compressing and lifting the column of material above it; and as we have shown that the value of T or T_1 must *always* and enormously exceed that of P, which is the vertical pressure, it follows that if P varies at different places in the shell, crushing will take place by vertical deformations and very readily.

95. Were the shell absolutely homogeneous and isotropic as to its material, still crushing must somewhere occur as soon as the pressure there had reached the limit of cohesion. But we must, as it appears to the writer, suppose the solid earth shell, however thick, to be heterogeneous, and discontinuous or fissured more or less at every depth, until the commencement of the plastic or viscous *couches* that intervene between its interior and the nucleus (whether that be liquid or only hot and soft relatively by heat) shall have been reached.

For the fissuring and shattering of the solidified crust, which began when it was very thin and was far more extensive and intense as it became thicker, and at a certain thickness (when the thermal equilibrium of the whole system had got more nearly to what it now is) began to decline, must have gone on, reaching continually further in depth as the thickness of the solid crust was increased by accretion to itself of more solidified matter at its inferior surface.

If, then, we admit the highly probable view that the solid crust of the earth at the present time is in *all* its parts more or less heterogeneous, if not in the nature of its materials, at least in the physical or molecular state of these at different points, there is no difficulty in admitting any amount of crushing and fissuring to be going on within it, and such crushing and fissuring *must* be local and irregular.

96. We have thus proved that localized crushing of the rocky material of our earth's crust *must* take place; and it will not be denied that heat must be produced by transformation of the work expended in crushing.

97. But two great questions now require to be answered—namely, *how much heat* is produced by the crushing of a given weight or volume of rock, and whether the total amount of crushed rock, or of heat due to it, that we can estimate on admissible data as occurring in a given time (a year or 1000 years) be adequate to account for the volcanic phenomena we witness on our earth's surface, or estimate as necessary thereto. The answers to these must be based on experiment.

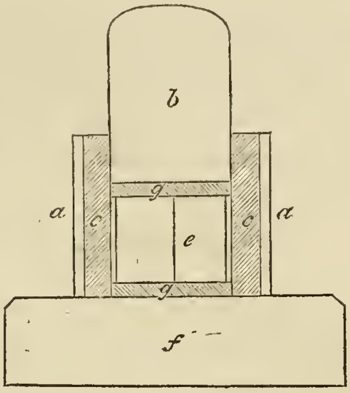
---

98. The mechanical work expended in the deformation or disintegration of a solid must all reappear either as heat or as external work of some sort.

In the case of very inelastic and easily deformed bodies, such as lead, Mr. HIRN has shown (Théorie Mécanique de la Chaleur, 2nd edit. part i. p. 58 &c.) that the heat evolved is almost *precisely* the equivalent of the work expended in deformation. No experiments (except those now to be detailed) have been made, however, so far as the writer knows, upon rigid bodies, such as rocks &c., to determine whether this is likewise true of them, although *à priori* the fact could scarcely be doubted.

99. A few preliminary experiments were made to ascertain if this was the fact. A short cylinder of thin iron (*a a*, fig. 8) was lined with hard wood (*c c*), an iron plunger (*b*) was fitted to the interior, the diameter of which just admitted, without touching at the arrises (*e*), a cube of 1 inch on the side. The cylinder placed on a plate of iron (*f*) had a circular piece of moderately thick paper gun-wadding dropped into it; upon this the cube to be crushed was placed; upon the top of the cube another piece of gun-wadding, and then, the plunger (*b*) being inserted and made to bear firmly on the matters below it, a known weight (25 lbs.) was dropped from a known and constant height upon the plunger so as to crush the cube to powder. The height necessary was fixed by trial, so that very little more work should be employed than was just necessary to crush the cube.

Fig. 8.



The material operated on was statuary marble, whose specific gravity was 2·710 and its specific heat 0·205. The apparatus, it will be seen, admitted of rapidly shaking out the powder of the crushed marble into a small known weight of water at a known temperature, from the rise in temperature of which the heat developed in the crushed material was inferred. The wood lining to the cylinder and the paper above and below prevented any very sensible loss of heat by conduction.

Eight good experiments were obtained with this little apparatus, the details of which it is needless here to give, as they do not pretend to any great exactness, the paper gun-wadding having in every instance to be thrown into the water with the crushed rock, and there being some little loss by conduction to the cylinder, and, indeed, the apparatus being on too small a scale. The results, however, showed that, on a mean of the whole eight, the heat produced was the equivalent of the work expended within about $\frac{1}{92}$ of the whole.

100. Prior to making these few preliminary experiments, the writer consulted his friend the late Professor RANKINE, and found that the views of that competent authority agreed with his own—that in the crushing of rigid material, such as rock, *almost the entire* mechanical work reappears as *heat*, the extremely small residue of external work being employed in producing vibrations of sound (or analogous to those of sound, though perhaps not affecting the ear) in the apparatus used for crushing or in the air around. Thus, even in the most rigid bodies, crushing begins by compression and deformation, however small; the mass then cracks, and then the discontinuous and irregular prisms and wedges soon suddenly and finally crush to powder. We *hear* when it cracks, and work is consumed in the little impulse that originates the sound; but its amount, as compared to the totality

of the work consumed in the crushing of a solid mass of hard rock to powder, is almost infinitesimally small.

101. We may therefore admit that, subject to the inevitable errors of experiment, the whole of the work consumed in crushing matter like rocks reappears as heat, or that in an experimental cube of the rock crushed to powder by a weight W, in pounds, descending from a height h, in feet,

$$\frac{Wh}{J}=H$$

is the number of units of heat developed, J being JOULE'S equivalent.

[The volume and weight of the cube crushed being known, we can deduce the work required to crush a unit in weight (1 pound) and in volume (1 cubic foot) of each rock thus experimented on.

102. If, then,

(1) $\frac{Wh}{J}=H=$the units of heat produced by the work of crushing 1 cubic foot of rock

(which, assuming the specific heat of water constant with respect to temperature, represents the number of degrees Fahr. in a pound of water, or the number of pounds of water raised 1 degree by the work of crushing), the weight of 1 cubic foot of water at point of maximum density being 62·425 lbs., and that of ice 57·8 pounds,

(2) $\frac{H}{62{\cdot}425}=T=$the temperature to which 1 cubic foot of water is raised by H;

and, taking the heat of liquefaction of ice as 143° Fahr.,

(3) $\frac{H}{57{\cdot}8\times 143}=$the number of cubic feet of ice at 32° melted to water at 32° by H.

Also, the total heat of steam of 1 atmosphere being $1146°=966°+180°$,

(4) $\frac{H}{62{\cdot}425\times 1146}=$the number of cubic feet of water at 32° evaporated into steam at 212°; also

(5) $\frac{H}{62{\cdot}425\times 180}=$the number of cubic feet of water at 32° raised to the boiling-point.

Further, if w be the weight in pounds per cubic foot, and s be the specific heat,

(6) $\frac{H}{ws}=t=$the temperature or number of degrees of heat by which 1 cubic foot of such rock is raised by H;

so that, if f be the temperature of fusion of any rock,

(7) $\frac{H}{fws}=\frac{t}{f}=$the number of cubic feet of rock capable of being melted from temperature 0 by H,

assuming that the specific heat of the rock is constant as respects temperature, and neglecting (as small and unknown) its heat of liquefaction*.]

[* This passage and the last two columns of Table I. are modified from what was originally presented to the Society.]

103. Great numbers of experiments have been made by engineers and architects upon the resistance to crushing forces of various rocks employed in building &c., some of which, such as those of GAUTHEY and RONDELET, are of great exactness; but unfortunately these are nearly all inapplicable to our purpose:—(1) because those experiments being made with a view to structural purposes, the recorded crushing-pressure is very commonly taken as that at which the specimen of rock first begins to crack or give way; (2) because no reliable record is found of the height through which the surface producing the crushing-pressure has descended between its level of first application and that of the mass of powder produced, so that we have an unreliable and always too small value for W, and none at all for h; (3) the experiments recorded have been generally made on very small specimens (cubes of 1 centimetre or of 1 inch on the edge), and of rocks the lithological characters of which are imperfectly handed down.

104. It was therefore necessary to institute a completely new and independent series of experiments, and upon as large a scale as that for which competent apparatus could be procured.

The rocks to be experimented upon being reduced by the marble mason or lapidary's tools to exact cubes, or parallelopipeds as nearly cubes as possible, it is obvious that experiments for determining the work of crushing may be conducted either, as in the writer's preliminary ones, by the free descent of a weight just enough to crush, or by the steady increase of a load until the crushing in each case has occurred.

The latter is greatly to be preferred, not only as avoiding some conceivable sources of error in crushing by *impact*, but for the convenience afforded by the increase of a steady pressure up to crushing when operating upon a large variety of different rocks.

105. Through the obliging kindness and zeal for science of JOHN RAMSBOTTOM, Esq., Engineer, and by permission of the Directors of the London and North-Western Railway, the writer had fitted for his purpose, and placed with a staff of men at his disposal, a magnificent machine constructed from Mr. RAMSBOTTOM'S design for the locomotive works at Crewe; and not only to those gentlemen, but to W. M. MOORSOM, C.E., of the same works, are his best thanks due for the very efficient assistance in every way afforded him.

106. The testing-machine at Crewe thus employed consists of a large wrought iron balanced lever, as seen in Plate IX., so constructed that it can be applied to compression, tension, or torsion, the load being produced by the flow of water into an iron cylindric vessel suspended to the long arm of the lever, the weight of which at known temperatures is registered by an index at each instant. This simple form of testing-machine possesses great advantages in accuracy and certainty, as to the load actually visited upon the object, over any of the complex machines in which the production of the load or its registration is conducted through a *series* of connected levers.

By shifting the fulcrum the lever could be altered in power at pleasure from 10 : 1 to 20 : 1, and its own weight could be balanced so as, if desired, to form no part of the load visited on the specimen. The strength of the parts is sufficient to admit of a crushing-strain of 80 or 90 tons with safety. The largest size was chosen for the cubes of stones to be crushed that this limit would with safety allow. A cast-iron cage or frame, shown in Plate IX. fig. 2, was prepared to receive each cube when exposed to pressure, which was applied by a cylindrical steel plunger moving freely in a deep cylindrical hole bored in the upper part. The lower part of the cage consisted of a flat steel plate upon which the cube of stone was placed, when the lower end or opposite face of the plunger applied itself to the top of the cube.

Thus the pressure upon the cube was preserved rigidly in the one vertical direction, whatever might be the motion (through a small arc) of the bearing edge of the lever itself upon the summit of the plunger. A small hydraulic press fixed between the fulcrum of the lever and this cage enabled the lever (and load if required) to be raised off from the head of the plunger at any time, and also enabled the cube about to be crushed to be conveniently placed between the faces of the crushing-cage without shock or any pressure acting upon it, except the small weight of the plunger itself; after which, by letting the water slowly out of the hydraulic-press cylinder, the bearing edge of the lever was brought gently and without jar or shock upon the head of the plunger, and the successive increments of load thereon then proceeded with.

The crushing-cage admitted of very precise measurements of the vertical distance between the crushing faces (*i. e.* that of the plunger and of the plate on which the cube was placed) at any instant.

Those distances from the commencement to the conclusion of each experiment were measured with great exactness by means of "distance callipers," with multiplying arms (on the same principle as "proportional compasses") increasing the indication tenfold, and provided with graduated arcs and verniers made by BECKER (now ELLIOTT Brothers), the indications being controlled by ordinary beam-calliper measurements read off from a steel diagonal scale. These measurements admitted of being made within less than $\frac{1}{1000}$ of an inch.

107. The following selection of rocks was made as tolerably well representing lithologically the whole series in depth of the earth's known crust from the least to the most rigid and coherent formations, viz. :—

Rocks experimented on.

1. Oolite.—Caen and Normandy.
2. Oolite.—Portland stone.
3. Dolomite.—Magnesian limestone, Yorkshire.
4. Sandstone.—Bradford, Yorkshire.
5. Sandstone.—Ayre Hill, Yorkshire (fine texture).
6. Sandstone.—Bramley Fall (hard millstone-grit).
7. Carboniferous limestone.—Devon marble.
8. Cambro-Silurian.—Conway slate (North Wales).
9. Cambro-Silurian.—Bangor slate (North Wales).
10. Basalt (greenstone).—Rowley Rag, Staffordshire.
11. Red granite.—Dartmoor, Devon.
12. Grey granite.—Guernsey.

13. Syenite.—Mount Sorrel, Leicestershire.
14. Blue granite.—Aberdeenshire.
15. Grey granite.—Aberdeenshire.
16. Porphyry.—Furnace Quarry, Inverary, Scotland.

108. Of each of these sixteen species of rock, half a dozen cubes, each as nearly as possible 1·5 inch on the edge, were prepared. Each set of cubes was roughed out from the same selected block of stone, and brought to the exact cubic form and size by grinding by Messrs. FIELD and Co., of Westminster, by whose care, with the help of their fine stone-working machinery, the work was done in a very excellent manner.

A larger-sized cube than 1·5 inch on the edge could scarcely have been employed, as respects the harder rocks, with safety to the testing-machine; but it is believed that no series of crushing experiments on rocks has previously been conducted on cubes so large.

109. The cubes could not be produced of *precisely* the same dimensions; but all were accurately measured before crushing by the instruments described, and the results reduced to a common standard.

110. The most scrupulous care, however, was taken to secure two opposite faces in each cube rigidly parallel to each other, so as to avoid unequal bearing when being crushed; and this result was fully attained by cementing the whole of the cubes down upon a flat metallic plate, and grinding off the uppermost faces simultaneously by another like plate, and then reversing the cubes and cementing them down again by the last ground face, repeating the process.

The experiments were conducted at Crewe works in August 1870, Mr. MOORSOM, C.E., assisting at all of them. Three good experiments were obtained for each description of rock, in some instances more.

111. Each experiment was conducted in the following manner:—

The testing-lever being raised by the hydraulic press, the crushing-plunger was raised, by a small hand lever of wood, from the base-plate of the cage sufficiently to admit of placing the cube.

The cube was then placed on the base-plate centrally, or with its centre of figure truly under the axis of the plunger.

A square piece of the *thinnest* and most *hard*-pressed letter-paper was placed upon the top and bottom faces of the cube, the size of the squares of paper being 0·20 inch less than the edge of the cube, so as to allow a free margin of 0·10 inch all round each of these faces, the object being by this very thin film of more compressible material to neutralize any residual departure from absolute parallelism between the upper and lower faces, and so secure perfect uniformity of bearing, a method which was found to succeed perfectly.

112. The cube being in place, the plunger was gently and without shock lowered upon it; and in like manner the lever itself, by aid of the hydraulic press, was lowered so as to bear upon the head of the plunger. The weight of the unloaded lever was then per-

mitted to bear as a load upon the plunger, and through that upon the cube. This gave an initial pressure (which was varied according as the species of stone was harder or softer) of a few hundred pounds, usually about at the rate of 500 lbs. per square inch, by which all parts of the testing-lever and the crushing faces with the cube were brought into perfect contact and bearing.

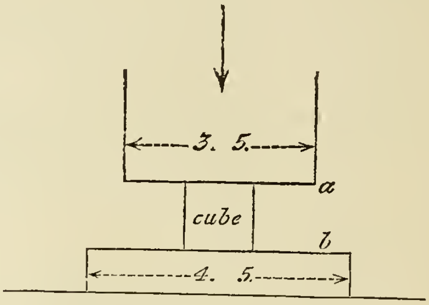
113. The dimensions of the cube having been accurately measured and noted before putting it into the crushing-cage, the altitude of the cube, or rather the exact distance between the crushing faces, was then taken. From the thinness of the papers on the top and bottom faces and the compression of these, this distance did not differ from the true vertical height of the cube by $\frac{1}{800}$ of an inch.

114. Water was now admitted in a small stream to the load bucket; and as each 1000 pounds of load was attained, the flow was stopped and the amount of compression of the cube taken by measurement between the crushing faces, as already described. The loading was thus continued until the first symptoms of disintegration were noticed in the cube, almost always showing itself by one or more extremely minute cracks in nearly vertical planes, or by a few fragments of powder detaching themselves from the sides.

At this stage the loading was stopped and the compression noted. The loading was then continued slowly until the cube finally gave way, crushing down before the descending plunger into absolute powder, which remained impacted together as a flat cake beneath the plunger, hindering its further descent.

115. The vertical distance between the face of the plunger and that of the base-plate (fig. 9) was then accurately taken, and this, deducted from the initial distance, gave the absolute distance through which the plunger had descended.

Fig. 9.



116. Had the entire volume of material in the cube remained always beneath the plunger in the form of a short cylindrical or round flat cake of powder impacted together and of equal density with the cube before it was crushed, inasmuch as the diameter of the plunger was 3·5 inches, the vertical distance *a b* (fig. 9) would have been for an exact cube of 1·5 inch=0·351 inch, which, deducted from 1·5 inch, would have given the descent of the plunger.

117. But the cubes were *not* all quite equal in volume, and the whole of the powder produced did not always remain impacted under the plunger, but some was thrown to a little distance. Hence it was necessary to measure in each case, to obtain the actual descent.

In a few cases, with the more rigid and elastic rocks, just before the final crush down, the cube split off one or more comparatively large undisintegrated fragments, which were thrown out laterally and escaped further action. Whenever any such fragments occurred means were adopted for their collection and preservation; and in such cases a correction has been applied to the result of the crushing based on this allowable assumption, that the work expended upon crushing that *portion* of the entire cube which was

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

To face page 187.

Table I.—General Results of Experiments on the Work and Heat of Rocks crushed at Crewe Works, 1870.

1.	2.	3.	4.	5.		6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27	28.	29.	30.	31
No. of Experiment	Character or Class of Rock	Specific Gravity	Weight per cubic inch and cubic foot	Dimensions of Cubes crushed.		Area of surface of Cubes	Weight per square inch at which first signs of yielding appeared	Mean weight per square inch at which first signs of yielding appeared	Crushing-weight per square inch.	Mean Crushing-weight per square inch.	Volume of Cubes.	Mean Volume of each sort of Rock	Weights of Cubes crushed.	Mean Weight of Cubes of each sort.	Actual Pressure at which Disintegration commenced.	Mean actual Pressure at which Disintegration commenced.	Actual Pressure at which the Cubes were completely crushed.	Mean actual Pressure at which Cubes of each sort were completely crushed.	Vertical Range through which the Crushing Pressure acted.	Work expended in crushing the Cubes	Mean Work expended in crushing Cubes of each sort.	Weight of large fragments thrown off on crushing.	Total Work expended in crushing the entire Cube	Mean Total Work expended in crushing the entire Cubes of each sort.	Mean Total Work reduced to crushing 1 cubic inch and 1 cubic foot.	British Units of Heat corresponding to mean total work of crushing 1 cub. ft. and 1 lb. avoird. of each Rock	Specific Heat of each class of Rock	Temperature in 1 cubic foot of Rock due to work of crushing	Number of cubic feet and pounds of water at 32° evaporated into steam at 212°	Volume of ice at 32° melted to water at 32° by one volume of Rock	No. of Experiment
		Water = 1000	$\frac{\text{Col. }3\times62\cdot4}{1000}$ for weight per cub. foot	Height.	Surface		$\frac{\text{Col. 15}}{\text{Col. 6}}$	$\frac{\text{Sum of col. 7}}{3}$	$\frac{\text{Col. 17}}{\text{Col. 6}}$	$\frac{\text{Sum of col. 9}}{3}$	Height × area of surface	$\frac{\text{Sum of col. 11}}{3}$	Col. 11 × col. 4 (weight per cubic inch).	$\frac{\text{Sum of col. 13}}{3}$		$\frac{\text{Sum of col. 15}}{3}$		$\frac{\text{Sum of col. 17}}{3}$		Col. 17 × col. 19	$\frac{\text{Sum of col. 20}}{3}$		$\frac{\text{Col. 20}\times\text{col. (13+22)}}{\text{Col. 13}}$	$\frac{\text{Sum of col. 23}}{3}$	$\frac{\text{Col. 24}}{\text{Col. 12}}$	$\frac{\text{Col. 25}}{J}$	Water = 1·00	$\frac{H}{W.S}=\frac{\text{Col. 26}}{\text{Col. 4}\times\text{col. 27}}$	$\frac{H}{62\cdot4\times1146}$	$\frac{H}{57\cdot8\times143}$	
			lbs.	in.	in.	sq. in.	lbs.	lbs.	lbs.	lbs.	cub. in.	cub. in.	lb.	lb.	lbs.	lbs.	lbs.	lbs.	ft.	foot-pounds.	foot-pounds.	lb.	foot-pounds.	foot-pounds.	foot-pounds.	Fahr.		° Fahr.		cub. ft.	
1.	Caen Stone, Oolite	2337																									0·281				1.
	Cube A		0·0867 145·8289	1·45	1·45 × 1·40	2·030	2463·0	1620·26	2955·6	2410·2	2·9435	2·9784	0·2552	0·2582	5006	3333	6000	4966·6	0·0883	529·80	439·92	none.	529·80	439·92	148·139 255,951·392	2·27 331·5		8·004	0·0046 cub. ft. 0·288 lb.	0·04008	
	„ B			1·43	1·43 × 1·47	2·102	952·3		1760·0		3·0060		0·2606		2000		3700		0·0858	317·57		„	317·57								
	„ C			1·44	1·44 × 1·41	2·073	1445·5		2510·0		2·9859		0·2588		3000		5200		0·0908	472·38		„	472·38								
2.	Portland Stone	2462																									0·265				2.
	Cube A		0·0888 153·6288	1·47	1·50 × 1·50	2·250	2400·0	3138·00	5711·1	5848·4	3·3075	3·2996	0·2920	0·2913	5500	7094	12850	13216·6	0·0950	1220·75	1259·13	„	1220·75	1259·13	381·603 659,409·981	5·5 854·1		20·98	0·0119 cub. ft. 0·774 lb.	0·1033	
	„ B			1·45	1·50 × 1·50	2·250	3555·0		5711·1		3·2625		0·2880		8000		12850		0·0958	1231·41		„	1231·41								
	„ C			1·46	1·50 × 1·52	2·280	3459·0		6123·1		3·3288		0·2939		7783		13950		0·0950	1325·25		„	1325·25								
3.	Magnesian Limestone	2571																									0·245				3.
	Cube A		0·0928 160·4304	1·45	1·52 × 1·47	2·234	3139·0	3699·00	6502·0	7400·0	3·2393	3·2140	0·3006	0·2975	7066	8000	14500	16333·3	0·0941	1365·32	1483·98	„	1365·32	1483·98	461·590 797,634·130	6·4 1033·2		26·28	0·015 cub. ft. 0·9 lb.	0·125	
	„ B			1·44	1·51 × 1·48	2·231	3811·0		6255·0		3·2292		0·2996		8000		13950		0·0850	1185·75		„	1185·75								
	„ C			1·46	1·48 × 1·47	2·175	4147·0		6470·0		3·1763		0·2923		9000		20550		0·0925	1900·87		„	1900·87								
4.	Sandstone from the neighbourhood of Bradford, Yorkshire	2478																									0·215				4.
	Cube A		0·0894 154·6272	1·46	1·45 × 1·48	2·146	9602·6	10979·00	14486·0	14011·0	3·1331	3·1047	0·2800	0·2775	20000	23017	31000	29783·3	0·0916	2839·60	2807·67	0·0868	4089·02	3952·37	1279·469 2,210,922·432	10·3 2863·4		86·13	0·04 cub. ft. 2·5 lbs.	0·346	
	„ B			1·46	1·48 × 1·45	2·146	10420·0		12476·0		3·1331		0·2800		22000		26700		0·0975	2603·25		0·0762	3506·45								
	„ C			1·45	1·47 × 1·48	2·102	12890·0		15071·0		3·0479		0·2724		27050		31650		0·0941	2980·16		0·0829	4261·63								
5.	Ayre Hill Sandstone, Yorkshire	2408																									0·233				5.
	Cube A		0·0869 150·2592	1·47	1·47 × 1·49	2·190	....	.....	6872·0	7301·0	3·2197	3·1905	0·2997	0·2772	....	....	15050	15968·6	0·0975	1467·37	1487·69	0·1093	2274·43	2386·17	748·214 1,292,913·792	11·1 1674·7		47·70	0·0234 cub. ft. 1·46 lb.	0·2026	
	„ B			1·45	1·50 × 1·47	2·205	....		7590·0		3·1972		0·2778		....		16706		0·0908	1516·36		0·1107	2517·15								
	„ C			1·45	1·48 × 1·47	2·175	6192		7442·0		3·1546		0·2741		15000		16150		0·0916	1479·34		0·1036	2366·94								
6.	Bramley Fall Sandstone	2506																									0·238				6.
	Cube A		0·0904 156·3744	1·45	1·50 × 1·53	2·295	crushed suddenly	......	5611·9	5040·0	3·3277	(3·2975) 3·3166	0·2908	0·2977	....	....	12850	11500·0	0·0991	1273·43	1295·32	0·1003	1713·36	1710·18	545·794 943,132·204	7·8 1221·6		32·84	0·017 cub. ft. 1·060 lb.	0·147	
	„ B			1·43	1·48 × 1·54	2·270	„		3631·0		3·2502		0·2956		....		8500		...	..		none.	..								
	„ C			1·45	1·48 × 1·53	2·270	„		5903·0		3·3055		0·2978		....		13400		0·0983	1317·22		0·0680	1706·99								
7.	Devonshire Marble	2717																									0·203				7.
	Cube A		0·0981 169·5408	1·47	1·52 × 1·49	2·264	11505·0	11708·30	17210·0	15684·0	3·3292	3·2780	0·3265	0·3215	26000	26000	38895	34938·0	0·0991	3854·49	3416·30	0·1135	5897·17	5770·46	1763·1157 3,046,663·9206	23·2 3946·4		114·679	0·055 cub. ft. 3·44 lbs.	0·477	
	„ B			1·47	1·48 × 1·51	2·234	11748·0		13791·0		3·2851		0·3222		26000		30755		0·0975	2998·61		0·1588	5905·06								
	„ C			1·47	1·49 × 1·47	2·190	11872·0		16052·0		3·2197		0·3158		20000		35155		0·0966	3395·67		0·1223	5535·43								
8.	Conway Slate	2733																									0·218				8.
	Cube A		0·0986 170·5392	1·43	1·50 × 1·52	2·280	....	9768·30	12234·0	12543·0	3·2604	(3·1935) 3·1601	0·3214	0·3148	....	21242	27895	27704·3	0·0633	1765·75	2051·87	none.	....	6973·21	2206·643 3,813,070·104	28·0 4939·2		132·85	0·07 cub. ft. 4·3 lbs.	0·596	
	„ B			1·45	1·50 × 1·51	2·265	8407·0		10877·0		3·2842		0·3238		19000		24584		0·0800	1966·72		0·2179	5998·49								
	„ C			1·43	1·42 × 1·49	2·116	11120·0		14519·0		3·0361		0·2993		23484		30634		0·0791	2423·14		0·2083	7947·93								
9.	Bangor Slate	2859																									0·201				9.
	Cube A		0·1032 178·4016	1·44	1·49 × 1·53	2·279	18512·0	15510·00	22944·0	18436·0	3·2827	3·2726	0·3387	0·3380	42000	34500	52095	41590·0	0·0783	4076·03	3438·34	0·1571	7580·00	......	2311·205 3,993,762·240	28·0 5173·2		144·20	0·071 cub. ft. 4·54 lbs.	0·613	
	„ B			1·45	1·48 × 1·52	2·249	...		...		3·2610		0·3365		...		....		....	..		....	....								
	„ C			1·47	1·51 × 1·48	2·230	12508·0		13931·0		3·2851		0·3390		27000		31085		0·0900	2797·65		none.	......								
10.	Rowley Rag Stone	2827																									0·204				10.
	(preliminary only) Cube A*		...	1·41	1·30 × 1·50	1·950	14358·0	......	29366·0	......	2·7495	...	0·2804	......	28000	......	57265	......	0·0791	4529·66	......	none.									
	Cube A		0·1020 176·4048	1·47	1·43 × 1·51	2·156	20930·0	24039·30	30830·0	29125·0	3·1741	3·2264	0·3237	0·3290	45000	52666	60285	63737·0	0·1650	6959·92	6465·43	0·1530	13244·70	11311·05	3515·08 [illegible]	44·0 [illegible]		[illegible]	0·100 cub. ft. [illegible] lbs.	0·926	
	„ B			1·47	1·50 × 1·50	2·250	24000·0		27761·0		3·3075		0·3373		54000		62463		0·0941	5877·76		0·1310	9610·13								
	„ C			1·47	1·49 × 1·46	2·175	27188·0		28784·0		3·1977		0·3260		59000		68463		[illegible]	[illegible]		0·1047	[illegible]								
11.	Dartmoor Red Granite	2652																									0·180				11.
	Cube A		0·0957 165·4848	1·48	1·49 × 1·45	2·160	13888·0	15161·33	18057·0	19389·0	3·1975	3·2634	0·3059	0·3123	30000	33666	39005	42965·0	0·1008	3931·76	4366·73	0·0623	4934·28	5055·27	1549·083 2,676,810·210	20·0 3467·3		116·39	0·049 cub. ft. 3·02 lbs.	0·419	
	„ B			1·47	1·49 × 1·50	2·230	14768·0		17984·0		3·2854		0·3144		33000		40105		0·0975	3910·23		0·0329	4363·82								
	„ C			1·47	1·50 × 1·50	2·250	16828·0		22126·0		3·3075		0·3165		38000		49785		0·1058	5267·25		0·0326	5867·71								
12.	Guernsey Granite (grey)	2858																									0·189				12.
	Cube A		0·1032 178·3392	1·475	1·47 × 1·50	2·200	18181·0	20903·33	27501·0	30123·0	3·2523	3·3186	0·3356	0·3424	40000	47000	60510	67715·0	0·0983	5948·13	6433·47	0·1641	11640·61	10857·92	3271·838 5,653,722·24	41·0 7323·4		217·24	0·1023 cub. ft. 6·39 lbs.	0·885	
	„ B			1·475	1·48 × 1·51	2·230	23317·0		32338·0		3·2963		0·3401		52000		72115		0·0858	6187·46		0·1180	9466·82								
	„ C			1·475	1·50 × 1·54	2·310	21212·0		30528·0		3·4072		0·3516		49000		70520		0·1010	7104·83		0·1319	11466·33								
13.	Mount Sorrel (red granite)	2653																									0·184				13.
	Cube A		0·0958 165·5472	1·48	1·48 × 1·53	2·260	18181·0	19970·33	24535·0	26201·0	3·3522	3·3357	0·3211	0·3195	40000	45000	55456	58988·0	0·0966	5356·17	5673·06	0·1123	8105·30	8141·38	2440·68 4,217,495·04	33·0 5463·0		182·27	0·078 cub. ft. 4·70 lbs.	0·6600	
	„ B			1·47	1·47 × 1·55	2·270	22467·0		23458·0		3·3486		0·3207		51000		53250		0·1025	5458·12		0·1002	7914·28								
	„ C			1·48	1·47 × 1·52	2·230	19282·0		30612·0		3·3063		0·3167		44000		68205		0·1041	7106·38		0·0468	8314·47								
14.	Aberdeen Granite (blue)	2707																									0·215				14.
	Cube A		0·0977 168·9168	1·48	1·53 × 1·56	2·390	19150·0	20125·66	25078·0	22681·0	3·3966	3·3669	0·3318	0·3318	43800	44600	57430	51985·0	0·0875	5025·12	4631·44	0·0920	6934·67	6584·819	1938·48 3,349,692·158	25·7 4339·0		119·2	0·06 cub. ft. 3·78 lbs.	0·524	
	„ B			1·48	1·54 × 1·52	2·310	23299·0		22780·0		3·4643		0·3384		51000		53365		0·0908	4840·09		0·0972	6776·13								
	„ C			1·48	1·51 × 1·49	2·240	17928·0		20187·0		3·3208		0·3253		40000		45220		0·0891	4029·10		0·1005	6043·65								
15.	Aberdeen Granite (grey)	2578																									0·196				15.
	Cube A		0·0965 160·9072	1·48	1·49 × 1·52	2·265	17256·0	16868·00	26373·0	22316·0	3·3522	3·3966	0·3233	0·3276	39000	38666	46045	51123·0	0·1025	4719·61	5176·67	0·1003	6183·43	7739·92	2278·726 3,937,638·528	30·5 5100·5		155·04	0·072 cub. ft. 4·41 lbs.	0·617	
	„ B			1·48	1·50 × 1·55	2·325	16000·0		22122·0		3·4410		0·3320		37000		51325		0·1025	5260·84		0·1136	7060·43								
	„ C			1·48	1·53 × 1·50	2·295	17348·0		24454·0		3·3966		0·3277		40000		56000		0·0991	5549·60		0·1111	8179·89								
16.	Furnace Scotch Clay Porphyry	2594																									0·186				16.
	Cube A		0·0936 161·8656	1·48	1·51 × 1·49	2·250	27111·0	26149·00	32781·0	30975·0	3·3285	(3·3366) 3·3411	0·3115	0·3123	61000	58833	73765	69786·6	not given.	.. ..	7108·54	0·5520		8941·735	2676·280 4,624,611·840	37·0 5990·4		198·97	0·083 cub. ft. 5·22 lbs.	0·721	
	„ B			1·48	1·50 × 1·50	2·250	27555·0		32540·0		3·3300		0·3116		62000		73215		0·1083	7929·18		0·0690	10149·35								
	„ C			1·48	1·50 × 1·51	2·260	23781·0		27601·0		3·3522		0·3137		53500		62380		0·1008	6287·90		0·0585	7734·12								

Mean Heat = 2448·50 Fahr. per cubic foot. 14°·93 „ lb. avoir.

Mean quantity of water evaporated by 1 cubic foot of crushed rock = [illegible]

Mean Heat = [illegible] Fahr. per cubic foot. 33°·24 „ lb. avoir.

Mean quantity of water evaporated by 1 cubic foot of crushed rock = [illegible] reduced to powder is to that which would have been necessary to reduce the entire cube to powder as the weight of the crushed part to the weight of the entire; so that the weight of those large uncrushed fragments having been ascertained subsequently, this correction was applied.

118. As the total descent of the plunger is in all cases small, less than 1·5 inch, the acceleration of its descent is not considerable, the rather as by the construction of the testing-machine a certain proportion of the crushing-pressure was relieved from the lever as soon as the plunger began to descend considerably, so that for the remainder of the descent the plunger was urged downwards principally by the weight of the heavy end of the large lever above it. Moreover, as each cube broke up at first into irregular prisms and wedge-shaped pieces closely adjacent to each other, which afterwards *crunched* down rapidly to powder, so the resistance to the plunger was not far from constant during its descent.

In this manner the entire series was gone through, only varied by very careful balancing off of the weight of the lever itself in the case of the very friable rocks, such as the Oolites.

119. The final pressure at the moment of crushing gives the value of W, and the descent of the plunger, subject to the correction described, that of h in the preceding equation.

120. In all the harder rocks, notwithstanding the close contact of the large mass of metal in the plunger and base-plate, the heat produced by the crushing down was easily perceptible by the hand, and was so great in the case of some of the granites and porphyries as to heat the plunger and base so much as to oblige a delay to let them cool to the same temperature as before, and as they were at in all the experiments, viz. about 57° Fahr. Had it been practicable to exclude the daylight, there can be little doubt but that a flash of light would have been found to attend each such crushing.

121. The results, both immediate or direct, and those deduced from this laborious train of experiments, are comprised in the accompanying large Table, No. I. The specific gravities, column 3 in this Table, were obtained by the writer by weighing one of the spare cubes of each rock, first in air and then in water contained in a thin cylindrical glass jar with a ground circular glass cover, the weight of which, as also of its contents of distilled water at 60° Fahr., was known. This method, which is very much more rapid than the usually prescribed methods, is to be commended for all specific gravities of solids heavier than water.

122. The specific heats of these several rocks (column 27) were obtained by the method of mixtures operating also upon these cubes, which were heated in boiling water, and then immersed in distilled water at temperatures of 50° to 54° Fahr., applying the usual corrections for the glass vessel containing the fluid, the thermometer, &c.

So few specific heats have previously been determined for rocks that these may be found to possess some general interest.

123. In column 8 and column 10 are given the mean loads per square inch at which the first signs of disintegration and at which the final crushing to powder occurred,

and the differences are thus obtainable. These vary much for different classes of rock.

If, however, we take a mean of the pressures at which first disintegration occurred, and of the differences between those and the pressures of complete crushing, we shall find that $\frac{1}{3\cdot778}$, or about $\frac{1}{4}$ added to the pressure of first disintegration, gives that of final crushing to powder—a result of some interest to the engineer and architect, and one which enables us in some degree to compare our results with the largest and most accurate series of experiments that the writer believes had previously been made on the resistance to crushing of rocks.

124. He refers to those of Mr. GEORGE WILKINSON, Architect, given in his work 'On the Practical Geology and Ancient Architecture of Ireland' (Murray, 1845), which were conducted by that gentleman upon almost the entire series of the rocks of Ireland from the highest to the lowest. The reliability of these experiments is known to the writer, as he himself devised and constructed the lever-apparatus by which they were performed; and the experiments were made in the engineering works of the writer's late firm by Mr. WILKINSON. As Mr. WILKINSON's object was to obtain *constructive* data only, the crushing-pressures recorded are seldom those at which the specimen (which in every case was 1 cubic inch in size) was reduced to powder, but that at which it was disintegrated only, and hence the results are all, as regards our point of view, here too low. If, however, we add to the mean of each class one-fourth part, we shall approximate to results more nearly comparable with those we have here obtained.

The following Table gives WILKINSON's highest, lowest, and average results, together with the number of different quarries and total number of experiments from which each average was ascertained. This summary has been made by the writer, and is not to be found in Mr. WILKINSON's work.

Class of rock.	Crushing-weights in lbs. per square inch.			Number of quarries.	Number of experiments.
	Maximum.	Minimum.	Average.		
Limestones	27510	1344	15053	125	210
Sandstones	26670	1239	8183	31	82
Sandstones across beds	18790	1680	8864	33	42
Sandstones in line of beds	20650	2940	9824	29	36
Slates across beds	27370	5040	13930	9	13
Slates in line of beds	21770	6160	11285	11	18
Granites	13440	2310	6657	8	20
Basalts, metamorphic	48020	7140	19025	12	25

The granites of Ireland generally are very friable.

125. It may be interesting to add the following volcanic rocks on the authority of PRUDHOMME ('Cours pratique de Construction'):—

Ancient lava (*Volvic stone*) of Auvergne .	28,446	lbs. per square inch.
Vesuvian lava (date not given)	8,392	" "
Granitoid porphyry (Bazoche)	21,072	" "

126. Cast steel in small blocks (according to FAIRBAIRN) may stand without crushing 120,000 lbs., or above 120 tons per square inch, or about four or five times the crushing-weight of the hardest known rocks.

127. In column 24 of our Table the mean total *work in foot-pounds* expended in crushing each sort of rock is given, and in column 25 the *foot-pounds of work* needed to crush 1 pound avoirdupois and 1 cubic foot of each sort of rock are given.

Then in column 26 this is, by our formula $\frac{Wh}{J}$, reduced to units of heat for the pound and for the cubic foot of rock; and dividing these by the specific heats given in column 27 and by the weights per cubic foot in column 4, we find the temperature in equal volume of rock; and in column 29 we obtain the number of cubic feet of water at 32° Fahr. that can be converted into steam of 1 atmosphere, or 212° Fahr., by the heat evolved by the crushing of 1 cubic foot of each class of rock.

Lastly, in column 30 we have the cubic feet of ice at 32° melted to water at 32° by the heat due to the crushing of 1 cubic foot of each of the sixteen typical classes of rock.

128. These coefficients of heat and crushing-work for each class of rock may be grouped together in various ways, so as to obtain *mean* coefficients for groups of rock or formations succeeding each other in depth.

Let us endeavour to obtain such a mean coefficient for the entire depth of the solid crust of the earth of 100 miles in thickness.

129. The following Table of the probable average depths of the *known* formations of our earth's crust has been given by Professor S. HAUGHTON (Geological Manual, p. 91):—

		Geogr. miles.
Neozoic	Tertiary to Triassic	4·512
Newer Palæozoic . .	Permian to Devonian	4·458
Older Palæozoic . .	Upper and Lower Silurian	5·082
Azoic	Quartz rock, Roofing-slates, Primary limestone	4·333
	Total depth =	18·385

geographical miles, or rather more than 20 British miles.

130. Assume the first 100 miles in depth of the earth's crust to consist of 20 miles of the above rocks (which are all of about equal respective depth) and of 80 miles beneath of crystalline rocks, and of unknown acid and basic magmas, crystalline or not, of a nature analogous to our most rigid crystalline rocks.

We may group the rocks of our Table I. into the newer, or Nos. 1 to 9 (viz. from the Oolites to the Silurian slates), and the older, from Nos. 10 to 16 (or from metamorphic to granites &c.).

The mean coefficient from the first is 2449°, and from the second 5650°; and the last may be taken to represent all below the azoic rocks; we therefore have 20 miles in depth at 2449° and 80 miles in depth at 5650°, which gives a mean coefficient for the entire depth of 5010°.

131. This is, however, certainly below the truth; for the Devonian limestone and North-Wales slates (Nos. 7, 8, and 9 have coefficients almost or quite as high as several of the granites and quartz rock of Holyhead, as deduced from my experiments on its crushing, Philosophical Transactions, 1862) have a coefficient exceeding 5316°, or equal to granite (see Appendix), and constitute much of the deepest 5 miles of our entire 20 miles of known rock; and there is to be found no doubt a large increase of metamorphic rocks of the Rowley Rag (No. 10) class at the lower part of the known series.

It will therefore be a better approximation to group together all the rocks in our Table I. *except* Nos. 10, 12, and 16, which have the largest coefficients, and take the mean of these for the coefficient of the known or stratified rocks, and the mean of Nos. 10, 12, and 16 for that of all the crystalline or other rocks beneath.

We shall then have the mean for all, *except* Nos. 10, 12, and 16, =4110°, and for Nos. 10, 12, and 16=7060°, or for the whole depth

20 miles at 4110°,
80 miles at 7060°,

giving a mean for the entire depth of 6472° per cubic foot of rock.

132. A mean specific heat obtained in the same way from those given in column 27 gives 0·199 for the average of the whole 100 miles depth of shell; and from the specific gravities given in column 3 we deduce a mean for all the rocks experimented on of 2627. Taking that as the mean for 20 miles in depth, and assuming 2900 specific gravity for the 80 miles of denser rocks beneath, we obtain a mean specific gravity for the whole 100 miles of crust of 2842.

133. Whence we have the following numerical results:—

(1) H=6472 British units per cubic foot of crushed *mean* rock.

(2) $\frac{6472}{62 \cdot 425}$=103° Fahr.=the temperature to which 1 cubic foot of water at zero is raised by H.

(3) $\frac{6472}{57 \cdot 8 \times 143}$=0·783=cubic feet of ice at 32° melted to water at 32°.

(4) $\frac{6472}{62\cdot 425 \times 1146}=0\cdot 0904=$cubic feet of water at 32° evaporated into steam at 212°;

or if the water be already at 212°,

$\frac{6472}{64\cdot 425 \times 966}=0\cdot 107$ cubic feet evaporated into steam of 1 atmosphere.

(5) $\frac{6472}{177 \times 0\cdot 199}=183^{\circ}\cdot 74=$degrees of temperature by which 1 cubic foot of *mean rock* is raised by H.

Taking 2000° Fahr. as the fusing temperature of such rock,

(6) $\frac{6472}{2000 \times 177 \times 0\cdot 199}=0\cdot 0918=$the number of cubic feet of mean rock at zero fused by H.

If the rock be previously at 300° Fahr., then

$\frac{6742}{1700 \times 177 \times 0\cdot 199}=0\cdot 108=$the cubic feet of rock so fused;

and if the rock at 300° be only heated to 1000° Fahr., or to a bright red heat (the melting-point of silver),

$\frac{6472}{700 \times 177 \times 0\cdot 199}=0\cdot 262=$the cubic feet of rock so heated by H.

134. From (3) it follows that the heat of liquefaction of 1 cubic mile of ice at 32° melted is equivalent to the crushing work of 1·277 cubic mile of mean rock when transformed into heat.

135. We have now to describe the second series of experiments, viz. those for the determination of the total amount of contraction of mineral masses analogous to those which we may suppose constitute the solid shell and probably the greater portion of our globe, upon cooling from their temperatures of fusion, or above that by known amounts, down to that of the mean of our atmosphere.

The experiments or observations that have heretofore been made on the subject are of the most unsatisfactory character, and contain such elements of error as to be wholly unreliable.

BISCHOFF's experiments on the total contraction of fused basalt, trachyte, and granite, &c. (originally recorded in LEONHARD and BRONN's 'Neues Jahrbuch für Mineralogie &c.,' vol. for 1841, p. 565 &c., and vol. for 1843, pp. 1–54, the last containing the details of experiments by BISCHOFF himself) have been accepted merely on authority, and quoted by authors in book after book apparently without the details of the methods of experiment having been consulted in the original memoirs. Thus Professor W. THOMSON (THOMSON and TATE, Nat. Phil. p. 725) says, "BISCHOFF's experiments, upon the validity of which, so far as I am aware, no doubt has ever been thrown, show that melted granite, slate, and trachyte all contract by something like 20 per cent. by freezing," and proceeds to base on this erroneous coefficient a probable cause for volcanoes and earthquakes (pp. 725–727).

He can scarcely have looked at BISCHOFF'S own statements, or their insecure foundations would not have escaped his acute mind.

BISCHOFF'S experiments were conducted by two methods.

In one he fused the rock in clay crucibles holding only a few pounds, determined the capacity of the empty crucible by the weight of its contents in mercury, and the volume of the unfused rock by its specific gravity and weighing. He then fused the rock, and to obtain its volume when liquid he *dipped* the depth of the surface below the brim of the crucible by means of a graduated iron wire, and then permitted the whole to cool. He then filled up over the surface of the solidified rock with mercury until the iron dipping-wire touched the liquid; from the weight of this mercury he infers the volume of the contraction; and filling now the whole vacuity of the crucible with mercury, he obtains, by weighing and deduction of these latter volumes of mercury from that which the empty crucible originally contained, the volumes of the rock when fused and when cold.

Substantially this is BISCHOFF'S method; though for all his steps and apparent precautions his original lengthy memoir must be consulted.

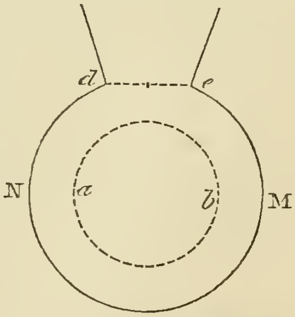
Now it scarcely needs to be shown at any length that reliable results by this complex and indirect method are perfectly impossible, even were not one condition which really vitiates the whole found to be entirely disregarded.

He was obliged to use mercury because his crucibles absorbed water; but the strong capillarity of mercury and its high specific gravity could not fail to introduce great errors in the deduction from its weight in such very limited volumes.

The supposed *expansion* of the crucible and enlargement of *its* capacity when heated was taken by endeavouring to measure the internal diameter of its brim when cold and when containing the liquid rock, and it is *assumed* the expansion affected all parts of the crucible alike, so that its capacity, in fact, was proportionate to the cube of this one imperfectly measured dimension. But this cannot be true, from what we know of the changes of form of pottery in baking, even were all parts of the crucible heated alike. But what of the *contraction* of the crucible, in common with all other earthenware, by heating, which depends not only on the temperature to which it is raised, but on the time of its exposure to the heat?

Of this which is certain to have largely affected BISCHOFF'S results, we do not find a word of remark.

Fig. 10.



BISCHOFF admits the difficulty of this class of experiment, and he seems in the end to have but little faith in his results, for he adopts another method suggested to him by ALTHAUS, an *Ober-bauinspector* at Saynerhütte. This consisted in filling a cast-iron globe (fig. 10) or shell, M N, provided with a funnel-shaped neck, with the fused rock. During the setting by cooling of the fused mass a solidified crust formed across the neck *d e*, and as soon as this had reached quite across it was assumed (upon the most manifestly insufficient grounds) that a solidified shell equal in thickness to half the diameter of the neck, or to $\frac{de}{2}$, had formed all round the interior of the globe, so that at that moment $a\,b$ was the diameter of the still liquid ball of fused rock within this crust. Cavities were formed within this by the final cooling and consolidation of the whole, which BISCHOFF supposes represent its total contraction. If, he says, the temperature of the liquid rock running into the sphere were exactly known, with the weight of the whole ball and that of $a\,b$ and the specific gravity of the whole, we should have enough to determine the total contraction. As it is he applies to his assumed ball $a\,b$ the unreliable coefficient of contraction deduced from his crucible experiments, and so arrives at a result.

In one instance, at least, even this result is further vitiated by an extraordinary oversight.

His calculation is thus:—

Diameter of the sphere N M 21 inches.

Thickness of the crust $\frac{de}{2}=\mathrm{N}a$ or $b\mathrm{M}-1\frac{1}{2}$ or 2 inches.

Diameter of the liquid ball $a\,b=21-1\frac{1}{2}$ or 2 inches$=19$, or $19\frac{1}{2}$ inches; average $19\frac{1}{4}$ inches.

Cubic content of this ball$=3733$ cubic inches.

Contraction$=3733\times0{\cdot}06$ (the coefficient of the crucible experiment)$=224$ cubic inches.

Now on BISCHOFF's own data the calculation is as follows:—

Diameter, as before, 21 inches.

Diameter of liquid ball $a\,b=21-2$ ($1\frac{1}{2}$ or 2 inches)

$=21-3$ or 4 inches,

$=$average 17 or 18 inches, or mean $17\frac{1}{2}$ inches.

Cubic content of ball of that diameter$=2786{\cdot}87$ cubic inches.

Contraction $2787\times0{\cdot}06=167$ cubic inches.

136. Mr. DAVID FORBES ('Chemical News' for October 1868) has noticed, though not in any detail, the general unreliability of BISCHOFF's results. He, however, endeavours to substitute for these deductions of his own from experiments still more fallacious, in support of his notion that the acid or basic silicates of which our earth's rocks consist *scarcely contract at all* in passing from the liquid to the solid state.

137. His facts are derived from the supposed dimensions of fused Rowley Rag stone (basalt) in the liquid state, and when again solidified after having been cast into moulds at Messrs. CHANCE's glass-works to form thin patent artificial stone, and from melted slags cast by himself into cast-iron ingot moulds of moderate capacity.

As regards the first, the moulds into which the fused rock was cast were formed of what founders call "dry sand," *i. e.* loamy sand, in which the impression of a wood "pattern" or model is made, the moulds being then dried and heated to something like a red heat, at which temperature the liquid rock is poured into them to fill the cavity.

Measurements of the wood "pattern," "often of some feet in length," and of the solidified counterpart in fused rock cast from it, according to Messrs. CHANCE's statement, proved them to be *precisely* the same size, from which it is inferred that there was no contraction at all in the rock by cooling.

Now this is exactly the same mistake that has been made by Dr. PERCY in his 'Metallurgy of Iron,' where he infers the coefficient of total contraction of cast iron from the difference between the size of the wood pattern from which the casting is made and the casting itself.

In both these cases the pattern, in order to be extracted from the damp "rammed up" sand, has to be "rapped" by the workman—that is to say, he strikes the pattern in all directions so as to make the cavity in the sand bigger than the size of the pattern, the difference being for clearance to enable the withdrawal of the pattern. If the sand mould be then dried and heated to something like redness, it will by expansion (on the whole, for there may be some little contraction at first on drying) cause the cavity of the mould to become still larger, and it is at this temperature that it receives the liquid rock.

Hence the equality in size between the wood pattern and the again solidified rock, even if *exactly* the fact, does *not* prove that there was *no* contraction, but that the amount of contraction was equal to the enlargement of the cavity of the mould, equal to the bulk of the pattern by the "clearance" given to the latter by "rapping" and by the further enlargement of the mould itself by heating; and as neither the volume of the clearance (which is never the same in any two cases) nor the enlargement by expansion (which may vary with the quality of the materials of the mould at different times, as well as with the temperature) are known, so no conclusion whatever can be drawn from those data as quoted from Messrs. CHANCE.

138. Then as to Mr. FORBES's own results, we surely cannot rely upon measurements made upon blocks of slag cast into iron ingot moulds of only 10 inches long, 6 inches wide, and 6 inches deep=360 cubic inches.

The contractions stated to be thus deduced at Eidfors Iron Works, Norway, of the slag (blast-furnace no doubt), which were from $1\frac{1}{2}$ to 3 per cent. (wide limits, the largest of which must yet be within the errors of these experiments), cannot be relied upon when we are left in the dark as to the temperature of the moulds, and therefore their actual size at the moment of consolidation, or whether any and what final cavities formed inside the solidified mass, and take into account the impossibility of measuring with any great exactness the true dimensions of such a small and even not rectangular block of slag with necessarily always a more or less rough and uneven surface.

139. Mr. FORBES's further experiments on basic slags from Staffordshire blast-furnaces, "cast into sand moulds," are vitiated through just the same reasons as those on the Rowley Rag.

140. Lastly, Mr. FORBES adduces some measurements made at Birmingham on blocks of cast glass cast in iron moulds, which either showed almost no contraction or (according

to Dr. Lloyd, of the Park Glass-Works) one of only $\frac{1}{272}$ lineal, on blocks the largest of which was but 40 lbs. weight, and not rectangular in form, being lenses in fact. We shall see further on what reliability there is in these last.

141. A few experiments on the expansion of rocks at high temperatures, but far below the fusing-points, by R. W. Fox, are recorded in the Philosophical Magazine for 1832 (3rd ser. vol. i. p. 338). Granite increased in bulk at a dull red heat by from $\frac{1}{52}$ to $\frac{1}{56}$, porphyritic felspar (from an "elvan course") the same; clay-slate augmented in size, in the direction of the cleavage, $\frac{1}{65}$ to $\frac{1}{77}$, by redness scarcely visible in the dark, and greenstone $\frac{1}{80}$. The whole of these statements look unreliable, and it is not clear whether he means cubic or lineal dilatation.

142. Bischoff's final results have been summarized by Mr. Forbes as follows:—

	Volume when in fusion.	Volume when cooled as glass.	Volume when cooled in the crystallized state.
Basalt	......	963	896
Trachyte	1000	888	818
Granite	......	888	748

so that the last is taken to suffer a contraction of about one fourth of its liquid volume!

The distinction made between the glassy and the crystalline states is, in this case at least, to a great extent arbitrary; for all mixed silicates which crystallize *segregate* in cooling into crystallized bodies which float in a surrounding glassy magma that never crystallizes (unless perhaps when *devitrified* by long heating), and it depends upon the relative proportions of the two, and upon the rate and other conditions of cooling, whether the intermingled crystals shall ever coalesce or the entire mass ever assume a crystalline state.

Beyond the experiments now noticed, the writer is not aware of any others involving high temperatures, although we possess some good and reliable data as to the expansion of some stony bodies at temperatures not much exceeding the boiling-point of water.

143. The writer therefore found it necessary to institute experiments himself as to the total contraction between liquid fusion or above it and solidification of such bodies as might represent tolerably closely in chemical and physical qualities the basic and the acid silicates of the natural rocks we are acquainted with.

The blast-furnace slags of the Barrow Iron-Works seemed to approach pretty nearly the former, and British plate-glass the latter.

144. The writer has to thank Mr. T. F. Smith, the Manager, for enabling him to conduct his experiments at the Barrow Works (near Furness Abbey, Cumberland), and Mr. Murdock, of the same Works, for aid in carrying them out.

145. At those Works red hæmatite only is smelted by coke fuel, with a very pure limestone as the sole flux, in blast-furnaces of the very largest class, urged by blast at a temperature of 700° to 900° Fahr. The slag formed when the furnaces are making fine grey pig iron (for the production of Bessemer steel) was that chosen for experiment.

It is usually of a light fawn colour, or of various shades of yellowish or bluish light grey.

The following are typical analyses of those slags:—

	A.	B.	C.
Silica	38·00	40·93	44·80
Alumina	10·00	9·49	11·21
Lime	42·00	42·01	36·05
Magnesia	1·65	0·68	1·24
Manganese protoxide	trace	1·83	2·12
Iron protoxide	2·08	0·64	0·84
Potash	1·60	0·59	1·56
Soda	2·03	0·57	
Sulphide calcium	2·45	2·72	2·35
Phosphoric acid	„	0·01	”

All these analyses show an excess from oxidation of the iron and manganese in the process.

The limestone used as flux contains about 97 per cent. carbonate of lime, with about 2 per cent. of silica, alumina, magnesia, and protoxide of iron, so that the greater proportion of these last found in the slag were contained in the hæmatite ores.

146. If we compare these analyses with the following of basalts &c., it will be seen that these slags in composition approach them closely:—

Basalts.

	A.	B.	C.
Silica	36·68	48·47	55·16
Alumina	14·34	30·16	7·42
Iron oxide	22·30		10·12
Magnesia	9·18	6·89	12·68
Lime	15·59	11·87	13·60
Soda	3·93	1·96	0·66
Potash	0·77	0·65	0·36

A and C are the extremes of 11 analyses of various basalts, and B is the normal basalt of Bunsen, from a mean of many analyses (Blum's Handbuch der Lithologie &c. 1860, pp. 180–192).

147. The difficulties in the way of obtaining any reliable measure of total contraction of fused rocks are undoubtedly great. Consideration as to their nature, and some preliminary experiments, caused the writer to conclude that the only method for approach to exactness was to operate upon very large volumes so as to extinguish many errors of experiment, and in such a manner that the volume of the fused rock could be directly *measured*, as well as its volume after solidification.

148. Three very large and thick hollow cast-iron cones, open at both ends (used at

Barrow for Bessemer steel ingot-moulds), were employed as receptacles and measures for the liquid slag.

The form of these and their dimensions are shown in Plate IX. fig. 4. Flat cast-iron base-plates were provided for these, so that when standing thereon with the wider end of the cone downwards it formed a close vessel, with its mouth or top free.

In the same vertical line at one side of one of these cones were bored partly through its thickness three holes, at top, mid height, and bottom, sloping downwards, to contain mercury or water, in which to insert a thermometer to ascertain the temperature of the mass of iron in the cone itself, the thickness of which, as seen by Plate IX. fig. 4 (No. 2), is great. The content of any one of these cones exceeds 8000 cubic inches, or above 4·6 cubic feet.

149. At successive periods each of these cones was fixed perfectly upright upon its base-plate, the latter being upon a secure and level foundation, and placed close to one of the blast-furnaces, and conveniently posited so that the slag could be run directly from the furnace into the cone, with arrangements whereby the run of slag could be instantly stopped upon the cone being filled.

The cone being at the temperature of the atmosphere at the place, about 51° Fahr., was then run up full of liquid slag, the run being stopped without difficulty precisely as the slag reached the level of the top or brim of the cone.

The slag in every case ran as liquid as very hot cast iron, and formed a pure unbroken and flat surface on the top of the cone, with a slight rounded edge due to capillarity all round the circle.

Means were taken that the stream of slag should come pure and unmixed with scoriæ &c. from the centre of the volume at the time contained in the furnace, which was for a short time previously "dammed up" to admit of its accumulation.

150. The slag so filled in continued for some time liquid; its top surface rapidly commenced to descend below the brim of the cone as the liquid slag began to lose heat by conduction to the mass of iron in the cone, and so to contract and the cone itself to expand.

Very soon, however, a solidified crust began to form over the top, the thickness of which was judged of by its resistance to penetration with a light pointed steel rod, and very soon after the before flat and level crust commenced to get hollow or concave towards the centre. This announced that a self-supporting crust had then formed also all round the cone, whose interior, however, was still liquid. This therefore marked the moment at which the true dimensions of the cast-iron cone itself must be known, as giving the true volume of the slag when consolidating at its surfaces. The dimensions of the cast-iron cones having been taken with accuracy when cold, *i. e.* at 49°, 51°, and 52° Fahr. respectively, we only need the temperature of the cone of cast iron to fix its capacity at the instant of incipient consolidation of the slag within it.

151. The cones were run up full of slag as rapidly as possible, the time of complete filling being from 4 to 8 minutes from commencement.

By separate experiments it was ascertained that water boiled in all three of the holes in the cone in 7 minutes after the commencement of filling, which may be taken as the time in which the mass of iron in the cone had reached 212° Fahr.

It was also found that the firm surrounding solid crust had formed in 22 minutes (average), and that consolidation commenced in about 20 minutes from commencement of filling. As the *difference* between the temperature of the iron cone and of the slag was very great during the whole of this time, we may admit that the increments of heat imparted to the cone were equal for equal intervals of time, and the cone gained 137° (or from 75° to 212° in these experiments) in 7 minutes.

152. Hence, as

$$7 : 137^\circ :: 22 : x,$$

the temperature of the cone at the period of consolidation of the firm crust may be taken at 430°·6 Fahr. But as the interior of the cone was hotter than the outside, and so exercised an expanding effect upon the outer portions, we must increase that number somewhat, and may estimate it at 450° Fahr.

153. The coefficient of expansion of cast iron, as given by LAVOISIER and RAY (mean of both) is

$$0{\cdot}00000618 \text{ for } 1^\circ \text{ Fahr., or } 0{\cdot}00278 \text{ for } 450^\circ;$$

and this is the coefficient of expansion which, applied to the dimensions of the cold cones, give those at 450°, as in col. 3, Table II., which are those that fix the volume of the slag at the time of its first consolidation.

154. The temperature of the liquid slag on entering the cone (sensibly the same as in the blast-furnace) was considerably above its fusing-point. It has been stated that the level of the top of the slag in the cone sunk rapidly, *parallel to itself*, and then, directly after a thin crust had formed, began to become *concave*. At this moment the mean depth of the top of the slag below the brim of the cone was taken by measurement. As the altitude of these cones is between four and five times the diameter of the brim, these measurements in *depth* afford very accurate determinations of volume, and it was found to average for the three experiments 130 cubic inches; and as 8160 is the mean capacity of the cones as taken cold, corrected for temperature, it follows that, taking the volume of the liquid slag as filled into the cones at *some* temperature above its fusing-point at 1000, the volume at its inceptive setting-point or fusing temperature is 983.

155. To approximate to what these temperatures really were, it was necessary to obtain that of the blast-furnace itself, which may be admitted as that of the slag issuing from it. The difficulties attending the use here of any form of pyrometer, to say nothing of the uncertainties of the indications of those instruments, finally determined the writer to employ POUILLET's method, or that of mixtures, by running out directly from the furnace a certain quantity of liquid iron into water of known weight contained in a large wooden vessel, and weighing afterwards to obtain the weight of the iron which had entered. The weight of water and of iron being known, with their specific heats, and

the temperatures of the water before and after mixture with the liquid iron, the temperature of the latter is obtained. The weight of water employed was always 400 lbs.

Three good experiments were obtained as follows:—

	Original temperature of water.	Temperature of water after mixture.	Weight of liquid iron.
1. . .	88°·7	188°·6	77·5 lbs.
2. . .	100·4	152·6	41·0 ,,
3. . .	111·2	170·6	43·5 ,,

No steam was given off by running the iron into the water, and the loss of heat to the wooden vessel was very small on so large a volume of water.

The specific heat of cast iron at the highest temperature given by SCHINTZ in his work on the blast-furnace (pp. 47–51) is 0·145.

If t° be the temperature lost by the liquid iron, t the increase of temperature of the water after mixture, w the weight of water $= 400$ lbs., w' that of the liquid iron, the specific heat of water being taken without sensible error as 1·000 within the above range of temperatures, and s being the specific heat of the liquid iron, we have

$$t^\circ = \frac{wt}{w's};$$

to which we must add the initial temperature of the water before mixture to obtain the temperature of the liquid iron.

Applying this, we have

t No. 1=100°, t No. 2=52°·2, t No. 3=59°·4.

No. 1 . . . . . t°=3470° Fahr.
No. 2 . . . . . t°=3525° ,,
No. 3 . . . . . t°=3735° ,,

And adding to these the initial temperature of the water, we have for the actual temperature of the liquid iron—

No. 1 . . . . . 3470 + 89° = 3559° Fahr.
No. 2 . . . . . 3525 + 100 = 3625 ,,
No. 3 . . . . . 3735 + 111 = 3846 ,,

the mean of which is 3677° Fahr., or 2011° Cent.

156. This determination coincides nearly enough with SCHURER'S results, who fixes the temperature of the zone of fusion in blast-furnaces at between 2650° and 2000° Centigrade.

It is, however, *something* below the truth, because at its intensely high temperature some heat must have been lost by the liquid iron on its way to the vessel of water, and some to the *bottom* of the wood vessel, with which it first dropped into *near* contact.

We may therefore estimate the actual temperature of the furnace at about 4000° Fahr., and the above 3677° or, in round numbers, 3680° as the temperature of the liquid slag as it entered the cones.

157. The solid conical blocks of slag cooling within the iron cones reached the atmospheric temperature in 12 hours from filling, parting with 3680° in that time; but consolidation commenced in 20 minutes (or $\frac{1}{36}$ of 12 hours) from running into the cones. If, therefore, we admit that the rate of cooling in the first 20 minutes was five or six times as great as the mean rate (which the laws of cooling would seem to justify), then the heat at the stage of incipient consolidation was

$$3680^\circ-(6\times103^\circ)=3062^\circ, \text{ or say } 3000^\circ.$$

158. After each cone of slag was sufficiently solidified, the cone of iron (with the slag within) and the base-plate were lifted together, and in the vertical position, by a crane on to a waggon and carried off on the furnace tramway and deposited vertically upon a level iron platform within range of another crane, and so left to cool. After 24 hours the iron cone was gently lifted off the cone of slag it contained; and owing to the contraction of the slag and to the taper form, widest at bottom, the parting took place very readily and without materially fracturing the cones of slag, which were found sufficiently regular in form and smooth in surface to admit of accurate measurement.

159. The admeasurements were then made by means of steel callipers and scales for diameters and heights, the former being controlled by circumferential measurements with a well graduated steel flexible strip or tape*.

160. On breaking up these cones no large segregated central core of matter different from the general mass was found, nor any large cavities. The exterior, where it had come into direct contact with the iron base or cone, was vitreous, and of a more or less bluish tint; but all the remainder showed itself, on examination with the naked eye or lens, as a tolerably uniform mixture of ash-grey crystals, more or less distinct, enveloped in a light greenish-yellow or pale-brown glass, the proportion of the crystalline to the glassy matter being very great, and greatest as we approached the centre, where in some places the grey crystals (resembling Wollastonite) were very clearly developed. The material operated on thus shows itself as a true crystallized rock, and not a mere vitreous mass.

---

* [Since the reading of this paper it has been asked why the writer did not determine the volume of these cones of slag by weighing in air and in water, or, more directly, by making water-tight the base of the iron cone with the cone of slag within it, and ascertaining the volume of water requisite to fill up the vacancy between them. Both these methods occurred to me, and, indeed, were those employed (with mercury) by BISCHOFF, but were abandoned by the writer, on the grounds of many practical difficulties, in favour of the method of direct measurement.

The cones of slag being intersected by large though closed cracks in various directions could not be disturbed or weighed in air, still less in water, without much hazard, and the apparatus needed must have been powerful and expensive to make. The making the cast-iron cones water-tight at the *inner* edge of their bases would have been extremely difficult, as the iron cone, as soon as it was raised a few inches, could not be lowered again by reason of numerous minute fragments of slag detached having fallen down between; some water under so large a head would have penetrated these cracks; and for either method so many sources of error would have arisen, and so many corrections would have had to be applied, that simple measurement appeared to promise the better results.]

TABLE II.—Results of Experiments on Slag Contraction, Barrow Iron-Works.

1.	2.			3*.			4.	5.	6.	7.
No. of experiment.	Dimensions of cones at 51° Fahrenheit.			Dimensions of cones at 450° Fahrenheit.			Cubic contents of moulds when cold. Temp. =51° F.	Cubic contents of moulds at a temperature of 450° F.	Volumes of cones of slag as measured at 53° F.	Total contraction =difference of volumes of columns 5 and 6.
	Diameter at top.	Diameter at bottom.	Height.	Diameter at top.	Diameter at bottom.	Height.				
	inches.	inches.	inches.	inches.	inches.	inches.	cubic inches.	cubic inches.	cubic inches.	cubic inches.
Cone No. 1 . .	14·25	16·00	46·00	14·28	16·04	46·12	8274·1550	8334·2310	7646·2269	688·0041
Cone No. 2 . .	14·40	15·75	45·44	14·44	15·79	45·56	8115·5705	8175·0005	7796·3884	378·6121
Cone No. 3 . .	14·30	15·80	45·45	14·34	15·84	45·57	8091·9931	8156·5373	7658·0758	498·4615
Mean values..	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	8160·5722	8255·2896	7700·2303	521·6926

Mean coefficient of total contraction, original volume=1000, from 3680° to 53°, as 1000 : 932·76.

Mean coefficient of contraction from fluidity to solidification, or (by estimation) from 3680° to 3000°, as 1000 : 983.

Or if volume at 53°=1000, at or near above the fusing-point it will be 1072 nearly.

Or if volume at 53°=1000, at the temperature of solidification it will be 1017·3 nearly.

161. On inspecting Table II. we arrive at the following results :—

The coefficient of cubic contraction for the slag between the temperature of its issue from the furnace and that of its incipient consolidation, or between 3680° and 3000°$=\frac{17}{1000}$, or the original is to the contracted volume as

$$1000 : 983 ;$$

and the coefficient of total cubic contraction, or that between 3680° and 53°, is nearly $\frac{67}{1000}$, or the original is to the contracted volume as

$$1000 : 933,$$

which is scarcely 6 per cent. in place of 20 to 25 per cent., as given by BISCHOFF.

162. We thus at once see that the difference in specific gravity, less than that between ice and water, between red-hot but solidified or even cold slag (or analogous fused rocks) and the same in liquid fusion is so slight that, coupled with the viscous or pasty condition which intervenes between the two states, it would readily admit of a thin or a thick terrestrial solidified crust being supported by and upon the surface of the liquid globe beneath, and lends no support to the view of terrestrial consolidation at the centre first, by continual subsidence of such crusts, as imagined by POISSON, nor to the notions as to the nature of volcanic action which Sir W. THOMSON has based on that assumption (THOMSON and TATE, Nat. Phil. p. 726 &c.).

163. A few experiments were made by the writer on the rate of cubic expansion of fragments (of a few pounds weight) at ranges between 55° and 600° Fahr., by heating them immersed in mercury in a glass vessel with a graduated stem, eliminating by calculation the expansion of the glass and the mercury, whose coefficients are well known.

These seemed to indicate that within these low ranges the expansion of the slag does not much differ from that of glass itself; but we cannot attach much value to experiments thus made.

---

* The columns 3 are deduced from the coefficient of dilatation of cast iron, taken=0·00000618 for 1° Fahr.

164. Admitting them for what they are worth, however, the curve (Plate X.) would seem to represent something like the increments of the coefficients of expansion of these slags at various temperatures, through the range from 0° to 3680°.

---

165. We now pass from the basic to the acid slags or silicates, of which British plate-glass may be taken as a type, as in chemical constitution not widely differing from the acid silicates in natural rocks, as a comparison of the following analyses shows :—

Plate-glass (Dumas, 'Chim. appl. aux Arts').

Silica	73·85	68·6
Alumina	3·50	1·2
Magnesia	,,	2·1
Lime	5·60	11·0
Oxide iron	,,	0·2
Oxide manganese . . .	,,	0·1
Potash	5·50	6·9
Soda	12·05	8·1

Gneiss (extremes of 4 analyses).

Silica	75·91	66·46
Alumina	14·11	16·20
Oxide iron	2·03	5·81
Lime	1·14	2·82
Magnesia	0·40	2·17
Potash	4·16	3·98
Soda	1·77	3·20
Water	1·16	1·59

Granites and Syenites.

	A.	B.	C.	D.
Silica	74·25	68·56	61·72	56·78
Alumina	11·58	14·44	13·57	16·64
Oxide iron . . .	2·41	5·04	7·16	9·58
Lime	1·08	3·85	5·88	5·12
Magnesia . . .	10·01	2·78	3·33	2·63
Soda		,,	3·12	5·30
Potash	,,	3·36	3·37	2·58

A and B are the extremes of five analyses of granites, C and D the extremes of four analyses of syenites.

Trachytes.

	A.	B.	C.
Silica	77·92	76·67	61·03
Alumina	12·01	14·23	17·21
Oxide iron	1·32		4·84
Lime	0·76	1·44	1·43
Magnesia	0·13	0·28	2·07
Potash	3·27	3·20	7·16
Soda	4·59	4·18	4·64

A and C are the extremes of five analyses, B Bunsen's normal trachyte of Iceland.

Porphyry, Pitchstones, Obsidian, &c. give closely allied results.

The preceding analyses of rocks are all taken from Blum's fine work, 'Lithologie oder Gesteinlehre' of 1860.

166. The writer has been enabled to obtain, from measurements made daily and habitually in the progress of British plate-glass manufacture, certain returns, from which the coefficient of contraction in that material, between a temperature not far below perfect fusion and that of the atmosphere, may be obtained, though not with perfect accuracy, yet with an approximation to truth as great as, or possibly greater than, by means of any small number of direct experiments.

167. In the manufacture of plate-glass the molten glass is suddenly poured out from the melting-pot upon the surface of a large cast-iron horizontal table. In breadth the mass is restrained from spreading laterally beyond two parallel strips of iron, fixed upon the table, the thickness of which determines that of the glass plate itself, which is produced by rapidly rolling over the heap of viscous glass a very heavy iron roller, by the passage of which the heap is evenly spread out, and a nearly rectangular plate produced, two of the sides being quite rectilinear and parallel, while the two other sides or ends are a little irregular.

The moment after the roller has thus acted, a superintendent applies to the sheet a pair of graduated beam-callipers (specially prepared), and measures from a mean point chosen in the upper and lower ends of the plate (which he marks at once *on the glass*) the mean length of the plate (the breadth being always the same), and the glass plate is as soon as possible slid off the table and removed to the "*leer*" to be slowly cooled. After it has become quite cold and is removed from the "leer" for storage, it is again measured by the same callipers applied to the same marked places; the width of the plate (known while hot by the space between the parallel rulers) is now also measured.

The surface of the plate is then calculated from those two dimensions, and the dimension and surface registered in a book, and so of every plate and of every day's work in the year.

168. Whether this be the universal practice of the trade or not, it has been so at the

Works of the Thames Plate-Glass Company at Blackwall; and the writer is indebted to the intelligent Manager, Mr. F. M. Waller, for extracts from his books for the manufacture of the year 1861, giving those measurements taken from about 40,000 superficial feet of plate-glass.

169. From a reduction of these it appears that the total surface of the hot glass being 36172 square feet, that of the same at atmospheric temperature was 35692. Therefore the linear dimensions were as the square roots of those numbers, or as 190 : 189, or

100 : 99·47,

whence the lineal contraction of British plate-glass, between its *very* soft viscous condition, or very near to but below its temperature of perfect fusion, down to that of the atmosphere, say 50° as the mean of the year, is $=0·53$ per cent.

170. But three times this is *quam proxime* its cubic contraction, or 1·59 per cent.

Hence 1000 in volume of glass very near its fusing-point became 984·10 at 50°, or the contraction in volume is thus $\frac{16}{1000}$, which is somewhat (though probably not much) below the truth, were we to take the glass at the higher temperature of actual fusion.

171. The *total* contraction of the Barrow slag to that of the plate-glass is thus as

1000 : 933 : 984,

or the total contraction of the glass in passing through its whole range of temperature from somewhat below fusion is about equal to that of the slag in passing through about 680°. The writer places much reliance on this result, based as it is upon so large an area of observation, and obtained by the repetition of the same sort of measurements by the same person for long periods, and being altogether of a character to cause minute errors to disappear from the final result*.

172. We therefore may be permitted to conclude that rocks consisting of acid silicates contract still less than those of basic silicates, and that a terrestrial crust of the former is still more capable of floating upon the same in fusion beneath.

173. As applied to our globe, it is highly probable that any inferences that may be drawn from either of these coefficients must be subject to the changes in volume that may arise in the mass cooled from changes in its molecular arrangement, such as that from the vitreous to the crystallized condition, data for which are unknown. Nor, in our ignorance of the proportions in which basic and acid silicates or other bodies constitute our globe, are we able to fix any mean coefficient for the whole.

We have now, however, to attempt such applications of the numerical results arrived at as in the present state of our knowledge may enable us to illustrate the theory of volcanic action here propounded, and in some degree to test its feasibility, if not its truth.

174. Sir W. Thomson has shown that in the agglomeration from the nebulous state of its particles from infinite distance there has been expended nearly 14 millions of foot-tons

---

* It may be mentioned that the Manager of the Thames Plate-Glass Works has never been given by the writer any information as to the object of his inquiry as to glass contraction, nor has he to the present day any knowledge of the coefficients for slag obtained by the writer.

of work upon every ton weight of our existing globe; and as that agglomeration was gradual, the greater part of this enormous energy was dissipated in space as heat, and is the first and most enormous dissipation of energy in the formation of our planet. The liquid globe became gradually a partially or (for any thing we can affirm to the contrary) now a wholly solid one, with a still heated nucleus.

175. The earth's diameter being at present 7916 British miles (adopting the coefficient of expansion as 933 : 1000), it was when liquid a globe 8105 miles in diameter, or at the temperature of incipient consolidation (supposing the whole globe ever was in that condition) 7957 miles in diameter; and if when liquid its mean temperature exceeded 4000° Fahr., the diameter would have been still greater.

The earth, therefore, between its period of liquidity and its present state has shrunk in diameter by 189 miles at the least. If we take as a rough measure of the energy involved in this, that it is equal to more than the work of the entire mass of the spherical shell of $94\frac{1}{2}$ miles thick dropping through 47 miles, we derive some idea of the prodigious energy dissipated or transformed in this second stage of our forming world.

If we assume $\frac{1}{4}$ the heat of the liquid spheroid to have been dissipated before the solid crust acquired such thickness as to transmit powerfully and to great distances tangential compressive strains due to contraction from that to something approaching its present state, that contraction represents work equivalent to 186,120 foot-tons for every ton of matter in the spherical shell comprehended between the radius of liquid fusion and the existing radius of our earth.

176. That portion of this immense energy not dissipated as radiant heat was, as we have seen, consumed as work in the deformation of the spheroid, in the plication of the thinner crust, and in the elevations by tangential pressure of the mountain-chains.

177. At length we arrive at the present condition of our globe, with its primitive energy almost exhausted, yet with enough remaining (in what comparatively is but the dregs or ashes) to carry on what seems to us the prodigious work of existing vulcanicity.

178. The earth is still a cooling globe; and whether we adopt ÉLIE DE BEAUMONT'S figures (0·0065), or THOMSON'S (0·0085), or J. D. FORBES'S (0·007 millimetres) for the thickness of the plate of ice which, covering the whole earth's surface, if melted to water at 32° Fahr. would equal the heat lost annually by our globe, the result will be that from 575 to 777 cubic miles of ice liquefied to water at 32° represents the annual loss of heat at present from our globe.

179. On the assumption that our globe has cooled from a much higher temperature and is still cooling, it is not deniable that at the remote geological epoch when the existing form of volcanic action began, no matter whether that was anterior to the Secondary epoch or when, the annual loss of heat must have been greater the further we go back in time, and must have exceeded 777 cubic miles per annum.

We shall, however, adopt THOMSON'S, as probably the nearest the truth. As the latent heat of fusion of ice is $=143°$ Fahr., and taking the cubic foot of ice to weigh 57·6 lbs., we have $143° \times 57{\cdot}6 = 8237°$ of heat in the cube foot of liquefied ice.

But we have already found that the heat developed by the crushing to powder of 1 cubic foot of mean rock is =6472 British units of heat.

Hence a cubic foot (or cubic mile) of ice requires 1·27 cubic foot or mile of crushed rock to liquefy it.

Therefore, if the total amount of all the heat annually lost by the earth were produced from crushed rock in the contracting crust (which it certainly is not), it would only require $777 \times 1{\cdot}27 = 987$ cubic miles of such crushed rock to produce it.

180. This seems a large amount; but it is as nothing compared with the mass of the globe.

If, for example, we suppose it all crushed within a shell of solid crust whose volume is but one fourth that of the entire globe, it is less than the one 65 millionth part of the volume of that spherical shell, and if spread over the earth's surface would form a mere film. There would therefore be nothing incredible were we to suppose that nearly the whole of the heat annually lost by the entire globe was equalled by that produced by the crushing of its crust by the contraction of the entire globe. Nor, as it appears to the writer, would the annual amount of contraction necessary to account for that amount of heat be inadmissible. It is certain, however, that the whole of the heat lost annually by the globe cannot come from such a source, but only a very small proportion of it, because the lost heat is the source of the contraction.

181. We appear obliged by the phenomena of hypogeal increase of temperature (perplexing as they are) to conclude that by far the largest proportion of the heat annually lost reaches the surface from a cooling nucleus, which surface, though in various degrees, it everywhere reaches; whereas volcanic activity is confined to narrow lines spread widely apart over the surface and parting with very little heat by lateral conduction.

The spheroidal wave of heat constantly passing upwards from the nucleus to the surface everywhere must be dissipated from the dry land by radiation, consumed in heating the water of the ocean and helping in the production of its currents, and is partly brought up by thermal waters which have infiltrated cold from the surface (see Appendix A).

182. Contraction due to this constant cooling (and that greatest in the nucleus, which is hotter and contracts most for given amount of cooling) is the necessary result, and with it crushing together of the crust as it follows down after the shrinking nucleus, and through the work expended in that crushing the production of a distinct source of heat, the amount of which must be demonstrably sufficient if it be the true source of vulcanicity.

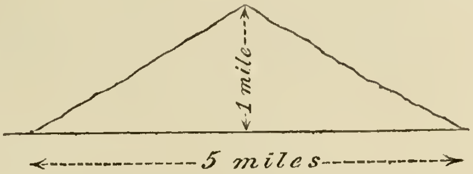
Let us then attempt to estimate, so far as our knowledge of the amount of volcanic action going on upon our globe may enable us, whether it be sufficient or not.

183. Volcanic energy as witnessed on our globe is mainly expended in three ways:—

1. Heat converted into work of elevation and ejection.
2. Heat employed in fusing or heating solid ejecta.
3. Heat wasted and dissipated in steam &c. at volcanic vents.

184. Had the writer been fortunate enough to have completed his projected pyrometric determination of the actual temperature deep in the Vesuvian crater (which the Royal Society aided some years back, but which the sudden alteration of the state of that volcano prevented), we should have been better prepared to make the following estimation.

Fig. 11.



185. All the volcanic cones upon our globe may be averaged as each equal in volume to a solid cone of one mile in height above the base of five miles in diameter; for while many are far below this height, and the majority of those measured do not reach this elevation, all the loftiest cones (above sea-level), such as Cotopaxi, &c., stand upon elevated tablelands or plateaux not volcanic or but covered skin deep with volcanic matter, and so have only a real elevation as volcanic cones of about 5000 feet. Thus Cotopaxi stands on the plain of Quito, 9000 feet above the sea. Antisana and two or three others only upon the whole globe appear to be exceptions; but it is very doubtful whether any of these cones really rise from sea-level; and the number is so small of these cones reaching 10,000 feet and upwards as not materially to affect the result.

186. The volume of one such cone (5 miles base × 1 mile high) is 6·54 cubic miles. As all volcanic cones are mere "cinder tips," masses of dust, lapilli, and scoriæ, to which the volume of solid lava beds bears a very small proportion, so we cannot take the average specific gravity of their materials at probably more than 2·0, or 0·05 of a ton per cubic foot; so that in one such cone we have 48,133,730,304 tons, to elevate which to the height of the centre of gravity of the cone 0·25 mile above its base requires 63,536,524,001 foot-tons; and as there are 2°·9 or nearly 3 British heat units in a foot-ton, dividing the above we obtain 21,178,841,333,760 British units of heat equivalent to the work. But we have found that one cubic foot of crushed (mean) rock evolves 6472 such units, dividing by which we obtain 3,272,370,686 cubic feet of such crushed rock to perform the work, which is $\frac{100}{4498}$, or less than $\frac{1}{45}$ of a cubic mile of crushed rock to perform the lifting work from base of the cone; or if we suppose it lifted from 10 miles deep below the base of the cone, then $\frac{40}{45}$, or less than 1 cubic mile of crushed rock.

187. As respects the heating and fusing work, the observations made everywhere on volcanic cones indicate that but a very small proportion of their total mass has been fused, the rest having been merely heated. It is probably below the truth to assume that there is twenty volumes of such heated matter (dust, lapilli, scoriæ, &c.) to one of fused lava.

The whole of this material, before being exposed to volcanic heating, exists at the hypogeal temperature due to its depth.

We may assume this temperature as above 300° Fahr., or that due to from fifteen to twenty thousand feet depth, that the *heated* material is raised to 1000° Fahr. (the melting-point of silver) and the *fused* material to 2000° Fahr. (that of liquid cast iron) from the initial temperature.

188. It follows from equation (6) that 1 cubic mile of crushed *mean* rock will thus heat 0·262 cubic mile of the heated material, or will fuse 0·108 cubic mile of the fused material, the specific heat of all being taken as the same.

And from the relative proportions of the dust and scoriæ to lava above assigned, we obtain as the result that 1 cubic mile of crushed *mean* rock will supply the quantity of heat necessary for 0·255 cubic mile of the mixed heated and fused material constituting a volcanic cone, or that 3·92 cubic miles of crushed *mean* rock is required for each cubic mile of volcanic cone.

Hence each such cone of the volume previously assigned requires $6·54 \times 3·92 = 15·636$ cubic miles of crushed *mean* rock for its heating work.

We have to add to this the lifting work as previously found $=0·888$ cubic mile, in total $=16·524$ cubic miles of crushed rock.

189. We have further to estimate the waste. From the low average conductivity of rock materials (perhaps not $\frac{1}{30}$ that of silver) the loss of heat by conduction to the walls of the volcanic focus and tubes to surface may be taken as insensible. The main source of waste is in heat units expended in producing steam, that yields no effective action in lifting or is spent in aërial ejection above the crater.

190. We have no data for more than a probable conjecture as to what may be the average amount of this. It may be remarked, however, that the sources of loss of effective action of the steam here do not resemble those in the steam-engine, in which, as HIRN has shown, about nine units of heat are wasted to one utilized, but rather resemble those of the gunpowder-gases in a cannon through windage and powder blown out unconsumed, &c., the losses from which ballistic experiments prove to be much smaller.

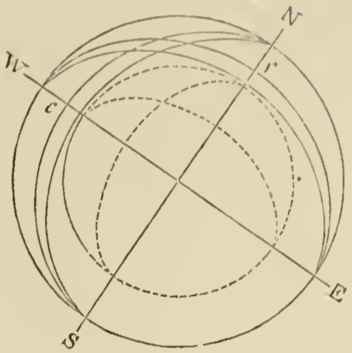
We shall allow, therefore, here that double the units of heat utilized in lifting are wasted, or that three times the lifting work is that actually expended, or $3 \times 0·888 = 2·664$ cubic miles of crushed *mean* rock.

191. Thus the lifting, heating, or fusing, and wasted work together, for one volcanic cone of the mean volume above assigned, demand a total of 18·3 cubic miles of crushed mean rock, or 18 cubic miles in round numbers.

192. Now there are about 400 volcanic cones known or stated to exist on the globe (a number sanctioned by HUMBOLDT and other good authorities), and averaging them all at the dimensions above, we find that $400 \times 18 = 7200$ cubic miles of crushed rock would have sufficed for their production.

193. [It thus appears that were the entire of the 987 cubic miles of crushed rock representing the *annual* loss of heat of our globe all consumed in volcanic energy, it would suffice to form all the volcanic cones upon our earth in less than *eight years*. Tens of thousands of years have been actually spent on the operation, from which we may see how excessively small must be the amount annually expended in vulcanicity.]

Fig. 12.



194. Taking now the earth's mean diameter at 7912 miles, two spherical lunes at right angles to each other, N*c*S and W*r*E, fig. 12, each of 180° chord, having a radial depth of 10 miles, and having no thickness at the extremities N S and W E, would at a width of only 255 feet at the equator and pole respectively be equal in volume to the 7200 miles; so that a circumferential contraction on the surface of the earth, if all in two orthogonal great circles not exceeding 255 *feet* on about 25,000 *miles*, is all we need to supply the volume of crushed rock within the first 10 miles of the surface, or vastly less if the contraction be extended down to a crust of 100 miles or 800 miles deep; and this crushed rock is not subtracted from the earth's volume, but simply transposed from beneath to its surface.

These 400 volcanic cones probably do not very inadequately represent the totality of volcanic action that has taken place since the Tertiary or even a more remote epoch; we know not how long that is; but if we spread the volcanic action over even a few thousands of years, we see what an almost infinitesimally small amount of annual crushing by contraction is sufficient to account for the phenomena.

It is not likely that future exploration will greatly add to the number of known volcanic cones, extinct, dormant, or active. Africa, the only great continent not yet tolerably known, seems to contain very few and probably none in the interior; Borneo, New Guinea, and the Antarctic continent may have a few; but it is improbable that 10 per cent. remain altogether to add to those already known.

Again, it is highly improbable (on grounds which it is impossible here to enlarge upon) that there are *many* submarine volcanoes, most probably none at all over the vast area of the bed of the deep ocean. One area alone has been discovered beneath the Atlantic Ocean, traversed as that has been for centuries now by ships continually.

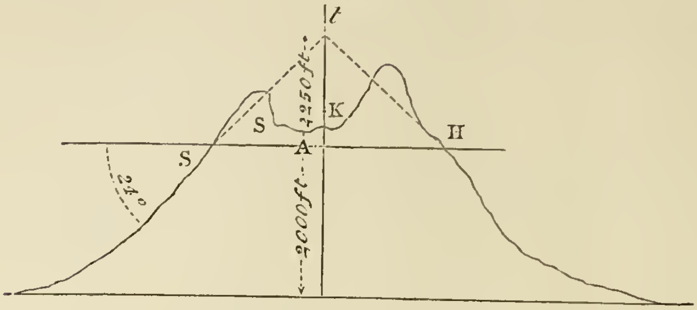
Some no doubt there are in shallow water, here and there, and more especially off the Pacific coasts of the American continent.

However, let us grant "scope and verge enough," and assume that one half as many more volcanoes as those we know of remain to be added, or that their total is 600 in place of 400; the result will be that in place of 7200 cubic miles of mean crushed rock we shall require 10,800 cubic miles—a volume still perfectly insignificant when spread over the vast volume of the earth's crust at 800 miles or even 100 miles thickness, and diffused in time over the unknown ages that have elapsed since the commencement of the existing forms of volcanic action.

195. We may illustrate the matter in another way, taking for basis the best observed volcano in the world, Vesuvius, and estimating the annual vulcanicity of the whole globe by the scale afforded by its very numerous eruptions.

Let it be assumed that the whole cone of Vesuvius above the level of the Hermitage, or below the Atrio del Cavallo, A, taken at 2000 feet above the sea-level, has been

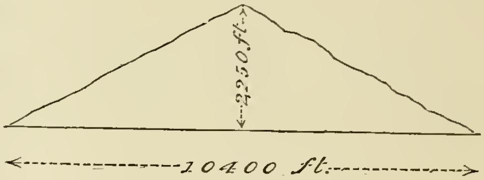
Fig. 13.



removed and replaced since the year 79 A.D. This is certainly above the truth, and exceeds Professor PHILLIPS's estimate (Vesuvius, pp. 248–9 &c.); for it takes no account of the mass of Somma, S, and the remains of the old mountain at the sea side, H (Pedamentina), still remaining, and lets these go against all the lava-streams since A.D. 79 and the wind-diffused dust, the united volume of which cannot but be much less than that of Somma alone from the Punto del Naso down to the level of the Hermitage.

The base-angle of the imagined cone S *t* H we take from SCROPE, and the writer's own observation of the angle of Somma at the level of the Atrio, at 24°, the total height of the Vesuvian summit *t* at 4250 feet, which gives for the altitude of the cone (removed more than once) 2250 feet and the diameter of base 10,400 feet, or for simplicity let us call it 10,560 feet or 2 miles. The altitude being 0·426 of a mile, we have 0·446 cubic mile for the volume of the cone. Let it be assumed that this volume has been *thrice* blown away and evolved again during the last 1800 years; then 1·338 cubic mile of melted or heated and elevated material represents the *useful* work expended on the volcano for the above period.

Fig. 14.



196. Supposing that work not to be paroxysmal (as it really is in every volcano) but spread uniformly over the 18 centuries, we have $\frac{1{\cdot}338}{1800} = 0{\cdot}000743$ cubic mile per annum, or 109,368,114 cubic feet per annum, raised 2000 feet from sea-level to the base of the cone and $\frac{1}{4}$ of 2250 feet further to its centre of gravity.

Taking, as before, the weight of the material at $\frac{1}{20}$ of a ton per cubic foot, we have for the lifting work 14,010,053,610 foot-tons, equivalent to 4,831,052,974 British units of heat. Dividing this by the units of heat in a cubic foot of mean crushed rock as before, we obtain 746,481 cubic feet, or less than $\frac{1}{200,000}$ of a cubic mile of crushed rock as necessary to do the annual lifting work of the cone itself. Allowing, as before, that double the number of units of heat are wasted of those usefully employed in lifting work, we have for the lifting work and waste together ·000015 cubic mile of *mean* crushed rock; but, as before, we assume the lift to be 10 miles (and not from sea-level to centre of gravity of the cone), or 21 times nearly the above.

Hence we have for the total work of the "cone building" in elevation, heating, and fusing (taken, as in the previous case, at 3·92 cubic miles of mean crushed rock to each cubic mile of volcanic cone material) as follows:—

Total lifting work and waste	·000315
Heating and fusing work on ·000743 cubic miles of cone material .	·00291
Total in mean crushed rock in cubic miles per annum	·000606

197. Now the total number of *active* volcanic foci known on our globe, as given by HUMBOLDT and others, is 270; let us take them at 300, and that all, small and great, when active are as active as Vesuvius, and produce the same average annual amount of equally heated or fused ejecta while in a state of activity. Both assumptions are greatly above the truth, probably, when we consider how many *very* small volcanoes there are (such as Stromboli) always active, but whose ejecta in a year (at present and for all history) have been insignificant in proportion to the few very great ones and the immense periods of dormancy of the majority. How many of the active volcanoes are on the average in eruption every year we know not; it will be admitted as probably above the truth if we assume that one in every three of them is so; that amounts to 100 cones always at work, at the rate of activity which we have taken for Vesuvius, which is notoriously one of the most frequently active on the globe*.

The final result, then, is that $\frac{300 \times \cdot 000606}{3}, = \cdot 0606$ cubic mile, represents in crushed rock per annum a considerable excess above the total existing annual vulcanicity expended on our earth.

198. [Another form of estimate may be employed. The following are amongst the greatest single flows of lava of which any attempt has been made to approximate to their volume:—

Graveneire	57 million cubic metres.
Pariou	33 million cubic metres.
Mont Sinuire	172 million cubic metres.
Come	344 million cubic metres.

These are all in Auvergne, as given by M. LE COQ (Epoques Géolog. d'Auvergne, t. iv.), who states the great uncertainty attending the cubation of every lava-stream, and deems that of Come as very doubtful.

Skaptar Jokul, 1783: 164 millions = 1640 millions of cubic metres (Voy. en Islande, &c.).

I omit another from the same work, affirmed, on utterly fallacious data, to have exceeded the volume of the entire mass of Mont Blanc.

---

* The catalogues that exist of the periods of activity and of rest of Iceland, Etna, and Vesuvius appear to contain the fact that in those cases at least the years of activity to those of dormancy do not reach one in three (see DAUBENY'S 'Volcanoes' and PHILLIPS'S 'Vesuvius').

Etna, 1669: 600 millions cubic metres, according to Borelli, but on very unsatisfactory data.

M. Cordier (Essai sur la Température de l'Intérieure de la Terre, &c.), after discussing several of the greatest lava-streams on record, including the above, and admitting their uncertainty, comes to the conclusion that 1000 millions of cubic metres exceeds the extreme volume of any lava-stream of which we have any evidence whatever.

This applies to lava-streams from volcanic action *proper*, and excludes those enormous wellings forth (*épanchments*) of basalt, trachytes, or other ancient lavas antecedent to the existing epoch of true or explosive volcanic action, such as have been observed in California, the magnitude of which often wholly dwarfs that of the very greatest volcanic outpourings.

The writer believes all the greater figures preceding, including M. Cordier's estimate, to be greatly in excess of the truth; but let us adopt M. Cordier's volume. Let us further assume that, in addition to this 1000 million cubic metres of material *all* fused, we have the same proportion as present supposed of *heated* but not fused incoherent material, viz. twenty times the volume of lava; and, lastly, that the entire is *lifted* from ten miles depth, and, in addition, to the summit of a cone higher than Hecla, or 5280 feet (=1 mile) more, and that, as before, we have double as much lifting work wasted as is usefully employed, *i. e.* three units of heat to do the work of one.

We then obtain the following results:—As there is 1·307 cubic yard in 1 cubic metre, 1000 millions of cubic metres =1307 millions of cubic yards fused from 300° Fahr., requiring 9·9 cubic yards, or nearly 10 cubic yards, of crushed rock for each cubic yard fused, $=10\times1307=13070$ millions of cubic yards of crushed rock.

Then for *heated* material raised from 300° to 1000°, we have $20\times1307=26140$ millions of cubic yards, requiring 3·8 cubic yards of crushed rock for each cubic yard heated, or $3{\cdot}8\times26140=993320$ millions of cubic yards of crushed rock.

Then for the lifting work, taking the density at 1·2 ton per cubic yard, or 1·2 ton $\times$(993320 millions+13070 millions) =1006390 millions of tons lifted; and as 3°=1 foot-ton, $\frac{1006390 \text{ millions}}{3^\circ}=335463$ million units of heat to lift it 1 foot high; and dividing by 6472 units of heat in 1 unit of volume of crushed rock, we require 50·3 cubic yards of crushed rock to lift 1 foot high, or $50{\cdot}3\times5280=265584$ million cubic yards to lift 1 mile high, or 11 times this for 11 miles, in all =2921424 million cubic yards of rock crushed.

Then for wasted heat we have double this, or 5842848 millions of cubic yards of crushed rock.

Summing up our results, we have:—

Fusing work	= 13070	million cubic yards.
Heating work	= 993320	"
Lifting work	=2921424	"
Wasted work	=5842848	"
Total in cubic yards of crushed rock . .	9770662	"

which, divided by the cubic yards in one cubic mile, 1760^3, or

$$\frac{9770662000000}{5451776000}, =1792 \text{ cubic miles}$$

of crushed rock to produce the whole.

The lost heat (in crushed rock) of our globe could produce this amount in less than two years. But such an eruption as the above does not occur probably in a hundred years, if such an eruption ever occurred at all.

But that is only the $\frac{1}{16285}$ part of the equivalent in mean crushed rock of the heat at present lost annually by our earth, which, as we have seen, is equal to 777 cubic miles of ice melted, or to 987 cubic miles of mean rock if crushed (992 cubic miles if we take the weight of a cubic foot of ice at 57·8 pounds).]

The volume of rock necessary to be crushed annually as thus found is (as in the former estimate) perfectly insignificant, when compared with that of a solid crust of 800 miles thick or even of 100 miles in thickness.

199. Finally, it is apparent that even were our estimates of past or of existing volcanic energy of our globe below the truth to such an extent that *ten times* the estimated amount of crushed rock would be needed to supply it, we should still have an ample storehouse of energy for it in the heat *now* annually lost by our globe, leaving still the greater part of that to be wasted by radiation into space.

200. The rock thus crushed *transfers* a portion of its own mass from a greater or less depth to the surface, and frees the cavities from which it is ejected of so much bulk, permitting them thus to close in and accommodate the dimensions of the shell to those of the shrinking nucleus beneath; but the mass is *only* transferred, it is not lost; and the transfer might have no effect whatever on the length of the day, even were its mass far greater.

Nor is the volume of rock crushed (to perform the volcanic work) necessarily all ejected; from any one point, on the contrary, much of it may cool again *in situ* with extreme slowness, and get recompacted into solid rock.

201. The writer believes, however, that a considerable proportion *is* ejected, and that this is, in fact, the function or final cause in the cosmos of vulcanicity. It is the means whereby a contracting solid crust gradually, and, though paroxysmally, on the whole harmlessly, adjusts itself to the dimensions of the nucleus shrinking away from beneath it; and were it not for this provision in the grand machine, or were the solid crust so rigid and constituted that its parts could not locally crush up, and the crushed matter be cleared out and thrown up to the surface, prodigious paroxysmal convulsions must result, with perhaps ages intervening between them, which would probably overturn the whole economy of the surface upon which the existence of organized life is now dependent.

Admitting fully within what wide limits of error estimates such as these alone admit of being made, the writer yet submits that he has proved to a high degree of probability that

1st. The crushing of the earth's solid crust affords a supply of energy *sufficient* to account for terrestrial vulcanicity*;

2nd. That the necessary amount of crushing falls within the limits that may be admitted as due to terrestrial contraction by secular refrigeration;

and if so, that the cause thus assigned is probably the true cause of existing volcanic action, will further appear on comparing the conditions, or some of them, that we can predicate must follow from such crushing action going on locally within the earth's solid crust, with some of the best known facts of observation of volcanoes themselves, to which we now proceed.

202. A primary characteristic of the view of volcanic action here proposed is, that it is only one phase of a *unique* force which has always been in action, though always decreasing in energy, since our planet was nebulous.

It introduces no hazy hypotheses of "reaction of the interior against the exterior," of internal distension by unknown gases, of chemical actions in the interior unsupported by proof of their existence.

It simply postulates an always cooling globe subjected to gravitation, and through these two undeniable premises it links together as the successive products of two forces only, refrigeration and gravitation, the formation of the land and ocean-beds, the elevation of mountain-chains, and volcanic action as now existing. Simplicity is the characteristic of every hypothesis upon which any true theory of the operations of nature has ever been produced.

203. The long prevalent view of geologists, that volcanic heat and steam explosive power arose from water making its way from the surface through an exceedingly thin solid crust to a universally liquid and fiery nucleus, is only tenable on the admission of such thinness of crust (probably 30 to 50 miles at most) as is quite incompatible with observed thermal conditions both on the surface and beneath it.

But if we admit a very much thicker solid crust (from 300 to 800 miles), it is incredible that surface-water should ever find its way through such a depth of dense material to the liquid nucleus; yet without water we can have no volcano, steam being admitted on all sides to be the ejective agent. The wholly gratuitous hypotheses of SCHALER, of Boston (Proc. Bost. Nat. Hist. Soc. 1866), of a liquid spherical shell between a solid nucleus and a solid crust, and of HOPKINS, of isolated liquid subterraneous lakes of lava within an otherwise solid globe, do not remove the difficulties as to their connexion with the surface-waters, and are exposed to insuperable objections to their existing at all.

204. SCHALER'S nucleus must be in unstable equilibrium as to position. Objections

---

* As this paper cannot be extended so as to include any special considerations of the effects as to fusion, chemical combination, or decomposition producible by a given amount of thermal energy acting on the substances within our earth's crust, it is here only possible to remark that in such considerations the effects of heating substances under pressure, as pointed to in the recent experiments of DEVILLE and GERNEZ and of FRANKLAND, all tending to show that the same amount of heat is more effective chemically as the pressure under which it acts is greater, must not be neglected; nor, on the other hand, those of M. CAILLELET (Les Mondes, 1869) on the limits to chemical action set by its taking place under pressure.

have been already urged to HOPKINS's lakes. Either the lakes or the liquid zone lie far too deep to be in communication with the surface-waters; and if once such a communication be supposed established, no reason can be assigned why the volcanic eruption thus brought about should ever end before either the limitless supply of water were ended or the reservoir of liquid lava completely pumped out.

205. Whether coming from liquid spherical shell or lake of lava, it is hard to see why the lava of the same volcanic vent drawn from the same reservoir should not always be the same.

Every thing indicates that the actual focus, where fire and water contend and produce volcanic action, is at no great depth below the volcanic vent.

The directions of the shocks felt during eruptions by observers not far removed from the axes of volcanic vents conclusively establish this. The centre of impulse of these shocks is coincident (on the whole) with the volcanic focus. Now, were this at a great depth, the emergent wave-paths around the base of the volcanic cone, and for considerable distances from it, must be almost vertical; houses &c. shaken down must show that they were so by forces suddenly throwing them upwards and letting them fall again in lines not very far from vertical. But such are not the facts even in the close neighbourhood of the great South-American and Oriental volcanoes; the shocks near the base are felt to approach nearer to horizontality than verticality, as is also the case with the best observed European eruptions.

206. But the writer is enabled to produce direct proof of this in the case of the greatest of European cones. In 1864, while exploring Etna, he noted and measured the directions of the cracks produced in a large number of more or less ancient church-towers and other buildings by the shocks of successive eruptions at various periods.

These observations were made at different towns or places, extending round a very large arc of the total circumference of the mountain. In every instance the masonry fractures pointed to a wave-path coming from near about the axis of the cone, and from a centre of impulse situated not very many miles below the level of the sea. This is conclusive as to the focus being not very deep; were it 800 miles deep, or half that, the injury done to towers and buildings must present a wholly different character, and the apparent verticality of the shocks could not escape universal notice.

207. But if the volcanic foci lie in lakes or perennial spheric sheets of liquid lava, then they must be, *ex hypothesi*, below the thick crust, and at an immense depth, and that nearly the same everywhere.

But water *must* reach that depth, great as it may be; and assuming the possibility of its access, it is difficult to see how, unless (notwithstanding the high temperature) it is compressed to a greater density than the liquid lake of solid lava, it can so get beneath or mixed up with the latter as to be able to blow it up in a *boursouflé* condition, and enable it to reach the surface through ducts or fissures of 500 or 800 miles in length, the walls of which are comparatively cold.

208. Recognized phenomena of different volcanoes indicate that they do not all come

from even nearly the same depth; but the depth must be nearly the same for all if the foci be in a spherical *couche* of liquid lakes left by refrigeration of the rest of the globe, as imagined by HOPKINS.

209. These difficulties disappear on our theory. The focus of heat may be at any depth, because crushing of the solid crust may occur at any depth, dependent on thickness of crust, *couche* of maximum tangential pressure or of greatest crushing resistance, &c.; and in general the tendency must be for the crushing simply to occur at no great depths from the surface.

210. The crushing is local, both as to surface and depth; where it occurs, being in the weakest parts of the crust, the fissures for admission of water are the most likely to be present.

211. The result of the crushing is to produce irregular masses, on the whole tending to verticality, of pulverized rock, heated more or less highly, that may extend to any depth within the solid crust; but it is only to such depth as water can percolate or infiltrate by capillarity that the deepest focus of volcanic activity can be found.

Below that the crushed and heated rock may exist, but it remains quiescent unless water reaches it or gases be evolved by chemical action increased by the heat. When water does reach such a heated mass of crumbled rock, it readily finds its way through the whole mass, which absorbs it as red-hot sand does water poured into it. Steam is produced if the temperature due to crushing be sufficient to raise both the crushed rock and the water (under the pressure of its superincumbent column and the resistances of the water-ducts) to the fusing-point, *boursouflé* lava results, and at sufficient elastic steam pressure is ejected, perhaps enlarging its own vent of issue by some preexistent fissure, by fusion as it rises, and subsequently by abrasion.

212. The researches of later years, and especially of JAMIN and DAUBRÉE, have shown that *infiltrating* water through the capillary pores of permeable rock may continue to pass through such against a heavy steam pressure; so that whilst the water continues to enter thus a heated cavity full of hot crushed rock, urged by an insistent head and by capillarity in the rock, no steam can escape back through the porous rock preoccupied by the water, just as a porous filtering stone under a head of water would continue to pass water into a fire, though the latter contained steam or gases under great pressure which could not pass out through the stone. We have thus all the conditions in our focus needed for the production of such variations of lava as we actually witness. Analyses have shown that while there is a great general similarity of constitution in lavas all over the globe, they yet do differ enough in constitution considerably to affect their degree of fusibility. We are also able to observe that some volcanic vents produce more fusible lavas than others, that some volcanoes produce little lava and much heated and pulverized material, and some nothing but the latter, no lava at all.

213. We can also see (in a good many cases at least) that the fusibility of the lava, and the proportion of its supply to that of unfused heated matter, dust, and lapilli, is referable to two (coexistent or not) elements of cause—the more or less fusible chemical

constitution of the lava, and the higher or lower temperature of the focus; and we can further see that the constitution of the lava has some relation to the successive lithologic formations in which the focus and vent are situated or through which they pass.

Siliceous crystalline rock and aluminous rocks alone, pulverized and fused, produce, for example, highly infusible lavas; siliceous and calcareous, still more those with certain portions of aluminous or ferruginous rock, much more fusible ones. The old but valuable experiments of KIRWAN are worthy of being still consulted on these points (KIRWAN's 'Mineralogy'), the fusibility in all cases also being largely influenced by the alkaline contents of the water, sea or fresh, that finds its way to the focus.

214. Now all these conditions are accountable for on the supposition of local and often more or less distinct foci of heated and pulverized rocks, differing in composition at different depths of the heated column.

We have also an adequate cause for the great differences of temperature at different and even closely adjacent vents, in that the heat at the focus is not derived from any invariable source at a nearly constant and uniform temperature, as in HOPKINS's notion, but is directly proportionate to the local tangential pressure which produces the crushing and the resistance thereto, and may vary to any extent at different points or at the same point at different times.

215. In this, too, we find an adequate and easy explanation of the absolutely non-periodic activity of volcanoes and their occasional sudden and violently paroxysmal action, as well as for their long periods of repose, and for the absolute extinction of some and the breaking out of new ones at points where none previously existed.

216. The secular cooling of the globe is always going on, though in a very slowly descending ratio. Contraction is therefore constantly providing a store of energy to be expended in crushing parts of the crust, and through that providing for the volcanic heat. But the crushing itself does not take place with uniformity, it necessarily acts *per saltum* after accumulated pressure has reached the necessary amount at a given point, where some of the pressed mass, *unequally pressed* as we must assume it, gives way, and is succeeded perhaps by a time of repose or by the transfer of the crushing action elsewhere to some weaker point.

217. Hence, though the magazine of volcanic energy is being constantly and steadily replenished by secular cooling, the effects are intermittent, and just provide from year to year the amount of force which is consumed in vulcanicity.

It is one of the many cases in nature in which the uniform development of a force results in variable and intermittent action as the effect of the force; it is steadily produced and accumulated, but unequally or paroxysmally expended. That such slowly accumulating pressure on local points of rigid solids does produce their giving way by crushing paroxysmally may be illustrated to the senses by pressing slowly and steadily a lump of sugar held by the fingers against a table; some of the points or surfaces in contact crush to powder, there is a momentary repose; we continue the pressure, or slowly or slightly increase it, more crushing, and another repose follows.

218. One cause for the extinction or long repose of volcanoes has been more or less perhaps recognized, they may get "drowned out:" the activity is dependent upon a certain balance between the supply of heat and the supply of water; if the latter become excessive, action dwindles to the solfatara or ceases altogether or for a time. But no prior theory assigns any cause for variability in the supply of *heat*: if that came from an immense liquid nucleus, it must be always the same and inexhaustible practically; if from the imaginary lakes, it might be slowly exhausted, but could not rapidly decline nor suddenly vanish, unless by the draining dry of its contents or of the heat of the whole lake.

On our hypothesis, however, we find an adequate explanation for the sudden production at a given spot and for the rapid exhaustion of the source of heat, and for its possible non-production again at the same spot or its production at another, adjacent or remote; in other words, for the long observed shifting of the position of volcanic vents in the course of time, as well as for the secular enlargement of the superficial areas within which their action occurs, as remarked by HUMBOLDT (Cosmos).

219. Lastly, it presents a complete solution to the question, Why should volcanoes present the linear arrangement they do on our globe, and why should they on the whole follow the lines of great mountain-chains? As manifestations of a common cause, contraction by secular cooling, but different in degree, the mountain-ranges heaped up by tangential pressure (as has been already stated) have been formed along lines of contrary flexure and of great fissuring and weakness in the earth's crust. But it is along such lines of weakness that the crushing by tangential pressure of the cooler and more rigid crust must principally occur; so that we may admit that at present the entire, or nearly so, of the tangential pressures produced by secular cooling are balanced by crushing *limited* to those great lines.

Hence the line of volcanic vents follows the mountain-chain:—1st, because there the fissures and vents of a shattered crust are chiefly found; 2nd, because it is in such lines that the chief crushing goes on as being the weakest places, so that there the heat for the volcano is provided. Here the "lake theory" signally fails. On what conceivable grounds shall we imagine these imaginary lakes arranged beneath great curved lines on the surface, as beneath the immense line of volcanoes that girdles the Pacific?

Why, if produced as residues of a frozen liquid nucleus, should they not rather be scattered pretty evenly in a *couche* beneath the whole surface of the earth? But if they be so, then the greater part of them must be hermetically sealed up from water, or, by hypothesis, we should have volcanoes dotted all over the earth; and this last is equally true as applicable to SCHALER'S liquid zone or a *universal* liquid nucleus.

220. Along such lines of volcanoes one vent or another may start into activity, according as the crushing energy beneath supplies more heat and pulverized material than another; and we find an explanation for the observed (or supposed to be observed) fact without calling in the very crude notion that one volcanic vent relieves another, all drawing from a common fiery ocean or from lakes beneath.

221. We also see that it is but a partial view to say the volcano is a safety-valve to the earthquake; for the volcano is really the safety-valve for the relief from time to time of the effects of contraction by cooling of our globe; and there is perhaps no more convincing consideration, indicating that the motive cause here assigned for vulcanicity is the true one, than is found in the fact that the assigned mechanism is one of nature's balancing adjustments, that the volcano's work is exactly proportionate to the crushing energy of the contraction that brings it forth, and which is thus drained off, gradually on the whole, though intermittently, in place of accumulating, until by the crushing together of vast masses at once of the earth's thick crust, cataclysm must arise destructive to the living creation. The action resembles that of the escapement of a clock, which lets the weight drop not uniformly, but slowly and gently, which if permitted to descend suddenly through a large space, must destroy the machine.

222. If, then, this be the true nature of volcanic activity upon our globe, it must be so for other planets, so far as their construction is analogous to that of our own.

And should future improvements of the telescope ever enable us to examine the surfaces of the other bodies of our solar system with sufficient exactitude, we shall be able in some degree to test this. At present, however, we can only apply it to our own satellite, and ask does it give us any information as to the peculiarities that its surface reveals to us in respect to bygone vulcanicity therein.

223. Without ocean or atmosphere, volcanic action such as we have upon our globe is impossible; it is possible, however, that the former vulcanicity of the moon was maintained until her whole ocean (which, in that case, must have been a very limited one) and her atmosphere had been wholly absorbed.

If that be so, as a precise balance is not probable, then it is likely there is still more or less unoxidized or otherwise chemically uncombined material in the moon.

But whether the vulcanicity of the moon be a completely spent energy or not, we find upon its surface elevations, and what appear to be craters, vastly exceeding in altitude and in width any thing upon our globe, and which seem perfectly abnormal as compared with the relative small size of the moon to our earth.

224. If vulcanicity be dependent merely upon communication, through the crust, with the liquid nucleus, partial or universal, and water-access to the same, there is no imaginable connexion between the *intensity* of volcanic action and the size of the planet on which it occurs; or if any, it is this, that the smaller planet cooling fastest may have a thicker crust, and so volcanic intensity should show itself less the smaller the planet is. But if it be, as here contended, a consequence of secular cooling, then the *intensity* will be greater as the progress of cooling is more rapid.

Now the cooling of any globe of like constitution and at the same distance from the sun must be directly as its surface and inversely as its mass—that is to say, as $\frac{D^2}{D^3}$, D being the mean diameter. Hence the rate of refrigeration of the moon from this cause alone must have been greatly more rapid than that of our globe, and hence the *intensity* of vulcanicity in a given time far greater also, because contraction of the crust is proportionate to the rate of cooling, and the heat produced by crushing of the crust proportionate to that rate.

We therefore see here a sufficient cause for the greater height of the mountain-ranges, as well as for that of the volcanic craters, in the moon than on our earth.

This greater height was no doubt further exalted by the diminished action of gravity in the smaller globe opposing elevation, as well as by the want of density though probable *great hardness* of the material constituting the moon.

225. The density of the moon is stated by HERSCHEL ('Astronomy') to be 0·536, our earth's density being taken as unity; and the mean density of our earth being about 5·5, it follows that that of the moon is about 3·0, which is about that of corundum, sapphire, quartz, and hydrous metallic silicates; so that, with the exception probably of a small and possibly metallic nucleus of greater density, the whole may consist of aluminates and silicates of great rigidity, and therefore producing very great resistances to contractile crushing, and hence great elevation of temperature at local points during cooling.

And this appears supported by the *Rillen* of MÄDLER, which to the writer's eye, with Mr. NASMYTH's best telescope, and also to that gentleman, appear as *cracks* or deep sharp-edged fissures in a rigid surface. The prevailing direction of these *Rillen* is about at right angles to the lines of elevation, which is just what we should expect if the elevating force were such as here indicated, viz. a tangential compression, for in that the lines of tension must be orthogonal to the lines of elevating pressure, and therefore the resulting cracks orthogonal to the lines of elevation.

226. It would be foreign to our direct purpose, and lead too far, to go into the probable causes that have led to the great relative diameters of the lunar craters.

Thus far we discern that volcanic activity generally is dependent upon the solid and liquid materials (elements) constituting any planet, upon their conductivity (rate at which they can part with heat), upon the mass of the planet, upon which both its original temperature (when all in fusion) and its rate of cooling are dependent, and upon its distance from the sun; possibly also upon whether or not it traverses in space regions of variable temperature.

227. In the sun itself we but behold vulcanicity in its earliest and most potent stage, that of the condensation and chemical exhaustion of a primordial world of vast dimensions, with its vulcanicity exhibited in (to the imagination) terrific grandeur. In our own globe we see it developed by quite the like train of causation acting differently at successive epochs, extending over time that we cannot measure, and now dwindled down to its present point, when it is but part of the beneficent machinery of our earth, to make it the safe abode of plants, animals, and man himself. In the moon we see it, after having passed through all its stages, died out and gone.

228. If, then, in what has been here advanced, and, so far as the writer's knowledge extends, for the first time, the cause assigned for volcanic heat, viz. the crushing of the earth's solid crust, accounts for *all* the phenomena, leaves none unexplained or

inexplicable, and introduces no consequences in themselves either inexplicable or contrary to observed facts, but all parts of the theory fit together with the facts so far as we observe them in nature, like the parts of a "dissected map" from which no one piece can be left out nor to it any new one added, then the writer submits that, on true principles of philosophy, the theory may be regarded as a true interpretation of Nature.

[*Note.*—The views of Babbage and of Sir J. Herschel as to the nature of volcanic heat have been alluded to at p. 158. It would have been difficult, however, before the development of the principles contained in the preceding paper to have shown the insufficiency of those views.

As they still linger in the minds of some geologists it seems desirable to advert to them here. Herschel's views are found, as stated by himself in letters to Sir Charles Lyell and Sir Roderick Murchison, in vol. ii. of the Proceedings of the Geological Society of London.

Briefly they may be said to embrace two distinct heads: 1st, subversions of mechanical equilibrium by sedimentary deposits unequally laid upon an extremely thin solid crust floating on a liquid nucleus; 2ndly, the consequences of such sedimentary deposits in causing a local rise in the geothermal *couches*.

The former we may pass, the existence of any such thin crust being inadmissible. As regards the latter it is enough to say that it fails to afford any adequate supply of heat sufficient to account for terrestrial vulcanicity.

The gradual rise of an isothermal *couche* in the way suggested by Herschel may possibly afford an adequate supply of heat to account for the phenomena of metamorphism, or more properly pyromorphism, but not for the play of any ejective volcano. Space forbids any proof of this here; but the nature of the objection may be illustrated by an example.

If we suppose, what certainly does not exist anywhere on our globe, that sedimentary deposits are going on continuously over some large area at the rate of 50 feet in depth per annum, it will require above 105 years to deposit a mile in depth; if we further suppose the conductivity of the superficial sediment the same as of that already deposited and deeply buried, the annual rise of any given geothermal *couche* beneath a given square mile of surface will be 50 feet, and the increase of temperature of the material just above the former level of the *couche* will be about 1 degree. The heat added, therefore, will be but one degree or thereabouts in a mass of sediment 50 feet in thickness and a square mile in area. This amount converted into units of heat is therefore the entire magazine of heat to supply the annual volcanic work per square mile, and, even on this extreme supposition as to rate of deposit, would prove wholly inadequate for the fusing and lifting work and waste required for the phenomena of active vulcanicity as now existing.

On principles derived from the above it may further be shown that making the very largest admissible estimate as to the total amount of sedimentary matter deposited annually over the entire globe, that amount would be altogether inadequate, upon Herschel's views, to supply the heat required for the annual vulcanicity of our globe as estimated in the preceding pages.

Herschel's views were apparently hastily struck off, and so far as they have been accepted by American and other geologists, have been so apparently on the credit due to the reputation of their author.

Had thermodynamics, however, been sufficiently advanced in Herschel's lifetime to have enabled him to test his views by their aid, there can be no doubt but that that illustrious man would have himself discerned the untenability of his theory.

In conclusion it may be added that the notion of some geologists that no supply of surface-water is necessary to existent volcanic action, but that the supply of water is derived from that liquid preexisting in vesicular cavities of the deep-seated rocky material, may be shown to present no adequate supply for the volume of steam in relation to the solid and liquid ejecta as seen at volcanic vents.—July 1873.]

Appendix.

A. *Thermal Springs.*

Authors on Vulcanology generally view thermal springs as one of the manifestations of volcanic action. That they are, in many instances, connected with volcanic vents, whose energies are nearly or for a time exhausted, is evident from such instances as the great hot springs of Auvergne or of Iceland; but that they are *not* related directly to volcanic agency in the vast majority of instances is equally obvious. In no case can we consider the surface-waters of supply descending many miles under ground; so that thermal waters, such as those of the British Islands and of a large portion of Europe, cannot be viewed as manifestations of volcanic activity, but as due to the surface-waters descending a certain moderate depth (which cannot be great, as no absolutely boiling spring is known except close to volcanoes), getting heated by the warmer beds below and reascending. We must therefore view the vast majority of the thermal springs of the globe in the light, not of volcanic phenomena at all, but as simply one of the means by which hypogeal heat is carried to the surface to be dissipated by radiation. It becomes an interesting inquiry in relation to our subject to estimate whether in this aspect the influence of thermal springs is great, or what proportion of the total heat lost annually by our globe is thus brought to the surface.

The writer has attempted this estimate in the following way:—

The thermal springs of Europe are those best known; next to these, perhaps, may be viewed those of India as catalogued by the Messrs. Schlagenthweit. Adopting Dr. Daubeny's catalogue ('Volcanoes,' &c.) for the former, there are in Europe 154 hot springs scattered over an area of 3½ millions of square miles, evolving 6577353752 cubic feet of water per annum at a mean temperature of 57° Fahr. above the mean annual temperature of the localities. In India (as comprehended in the above catalogue) there are about 100 hot springs scattered over an area of 1½ million of square miles, evolving 4345000000 cubic feet of water per annum at a mean temperature of 51° Fahr. above the mean annual temperature (taken for all India as 75° Fahr.).

These together, therefore, distributed over an area of 5 millions of square miles (of tropical and temperate latitudes) evolve about 10862353752 cubic feet of water per annum at a general mean (quantity and temperature both taken into account) of 54°·6 Fahr.

If, now, we assume that all the remainder of the dry land of our globe present like thermal springs in like abundance, then the total evolution annually from the 52 millions of square miles of dry land is 112968337520 cubic feet at 54°·6 Fahr. above the mean temperature of the localities. That is equivalent to 34336880705 cubic feet of water raised from 32° to 212° Fahr., or to 0·2332 cubic mile of water boiling under 1 atmosphere brought to the surface per annum.

If, now, from the insufficient character of our data, and especially as respects South America and Africa, we suppose that the above estimate does not comprise more than one half the volume of hot water really brought annually to the surface, or that the mean temperature of the hot water is below the truth, and if we double the result so as to include these, we find that the totality of the thermal waters of our globe does not probably exceed half a cubic mile of boiling water per annum, the equivalent of which in melted ice at 32° shows that the entire amount of hypogeal heat thus carried off is not the one thousandth part of the total annual heat lost by our globe, as taken at 777 cubic miles of ice melted to water at 32°.

Whether, therefore, thermal springs be viewed as mere adjuvants to the dissipation at the surface of hypogeal heat, or as products of volcanic heat directly and in *all* instances, their influence is insignificant, and does not affect the views contained in the text.

B. *Heat and work from Quartz-crushing.*

Derived from the work done in crushing quartz in Victoria Colony Goldfields. Taken from R. B. Smith's 'Goldfields of Victoria,' royal 8vo, 1869, p. 543.

Weight of each stamp-head.

		lbs.		lbs.
(1)	Ballarat district . .	336	to	896
(2)	Beechworth	448	,,	868
(3)	Sandhurst	560	,,	896
(4)	Marybois	448	,,	840
(5)	Castlemaine	280	,,	840
(6)	Ararat	560	,,	784
(7)	Gippsland	336	,,	896
	Average . .	424	to	860

General average = 642 lbs.

Each stamp-head falls.

	ft.		ft.					
(1)	0·583	to	0·833	50	to	80	strokes	per minute.
(2)	0·417	,,	1·333	45	,,	80	,,	,,
(3)	0·708	,,	1·500	45	,,	72	,,	,,
(4)	0·666	,,	1·000	60	,,	80	,,	,,
(5)	0·500	,,	1·250	35	,,	80	,,	,,
(6)	0·500	,,	0·833	60	,,	80	,,	,,
(7)	0·583	,,	0·917	70	,,	80	,,	,,
Average	0·5653	to	1·0951	Average 52·143	to	78·857	,,	,,

General average 0·8302 *foot* and 65·5 *strokes* per minute.

Weight of Quartz crushed per 24 hours by one stamp-head.

	lbs.		lbs.	Size of powder			
(1)	2016	to	7840	40	to	224	per square inch.
(2)	2240	,,	8960	65	,,	144	,,
(3)	1680	,,	6720	64	,,	130	,,
(4)	3360	,,	6720	60	,,	140	,,
(5)	2240	,,	8960	64	,,	160	,,
(6)	2800	,,	3360	100	,,	121	,,
(7)	3360	,,	4592	70	,,	250	,,
Average	2528	to	6736	66·143	to	167·000	,,

General average 4632 lbs.

General average 116·571 per square inch.

Horse-power given to work each head.

	H.P.		H.P.
(1)	1·00	to	1·50
(2)	0·75	,,	2·00
(3)	0·75	,,	1·00
(4)	0·83	,,	1·75
(5)	0·50	,,	2·00
(6)	0·60	,,	1·50
(7)	0·83	,,	1·87
Average	0·7514	to	1·66

General average=1·2057 H.P.

Actual specific gravity of Victorian Gold Quartz from Royal School of Mines:—

By their determination . . . =2·6307

By Mallet's determination . . =2·6224

Actual of Wicklow Quartz (Brett):

Mallet's=2·6214.

This is but a *mere contrast* as regards the conclusions here sought for.

Specific gravity of quartz on various authorities:—

Senft	(specific gravity)	=2·5 to 2·8
Zirkel	,,	2·6
Kirwan	,,	2·64 to 2·67
Beudant	,,	2·641 to 2·654
Huay	,,	2·670

Average of all 2·6469

1 cubic foot of water at 60° weighing 62·5 lbs.:

$$1{\cdot}0000 : 62{\cdot}5 :: 2{\cdot}6469 : x = \frac{62{\cdot}5 \times 2{\cdot}6469}{1{\cdot}0000} = 165{,}431 \text{ lbs. av.}$$

=weight of cubic foot of quartz.

The *specific heat* of silicic anhydride, $Si O_2$, is given by WATTS (Chem. Dict. "Heat," vol. iii. p. 32) as $=0\cdot19132$, water being unity; 0·179 by my determination of quartz from Wicklow, Ireland.

Specific heat of quartz 0·1719 (HERMANN) } GMELIN'S Handbook,
0·1913 (REGNAULT) } vol. i. p. 245.

Now the average of the whole data results in these:—

642 lbs. falling 0·8302 foot 65·5 times per minute for 24 hours,

Produces 4632 lbs. of quartz in powder,

116·571 meshes per square inch;

or 642 lbs. falling $0\cdot8302\times65\cdot5=54\cdot3781$ feet per minute for 24 hours,

or $24\times60=1440$ minutes $=78304\cdot464$ feet.

That is, 642 lbs. $\times78304\cdot464$ feet $=50{,}271{,}465{,}888$ foot-pounds, being the *work done* to crush to powder 4632 lbs. of quartz,

or $\frac{50{,}271{,}465{,}888}{4632}=10853\cdot08$ foot-pounds per 1 lb. of quartz,

or 10853·08 foot-pounds $\times165\cdot431$ lbs.$=1{,}795{,}435{,}877$ foot-pounds per cubic foot of quartz of specific gravity 2·6469.

Then, dividing by JOULE'S equivalent, we have

$\frac{1795435\cdot877}{772}=2325\cdot69$ degrees Fahrenheit in 1 lb. of *water* as the equivalent of the *crushing work* per cubic foot of quartz; or, as steam from water at 32° of 1 atmosphere and therefore at 212° contains 1146·7 units of heat, the work of crushing 1 cubic foot of quartz would vaporize at 212 degrees 2·028 lbs. of water, for

$$2325\cdot69 : 1146\cdot7 :: x : 1 \text{ gives } x=\frac{2325\cdot69}{1146\cdot7}=2\cdot028.$$

Now let us take the results, not from general averages, but from the *highest* and *lowest* data given, having regard to the fineness of the pulverized quartz produced, *i. e.* assuming that the average finest powder is due to the largest expenditure of power.

Then, first, we have from what precedes, that (*highest*) 860 lbs. falling 1·0951 foot 78·857 times per minute produces in 24 hours 2528 lbs. of quartz-powder of fineness to pass through 167·0 parts of a square inch,

or 860 lbs. falling $1\cdot0951\times78\cdot857=86\cdot356$ feet per minute,

or $86\cdot356\times1440=124352\cdot64$ feet per day of 24 hours,

which is 860 lbs. $\times124352\cdot64$ feet $=106943270\cdot4$ foot-pounds, being the work done to 2528 lbs. of quartz,

or $\frac{106943270\cdot4}{2528}=42303\cdot5$ foot-pounds expended per 1 lb. of quartz, or $42303{\cdot}5 \times 165{\cdot}431 = 6998310{\cdot}31$ foot-pounds per cubic foot of quartz; and dividing by $J=772$, $\frac{6998310{\cdot}31}{772} = 9065{\cdot}2$ degrees Fahrenheit in 1 lb. water as the equivalent of the crushing *work* of 1 cubic foot of quartz-powder of $\frac{1}{167}$ of a square inch of fineness.

Secondly, we have the *lowest* data, viz. that 424 lbs. falling 0·5653 foot 52·143 times per minute produces 6736 lbs. of quartz-powder of a fineness $=\frac{1}{66{\cdot}143}$ of a square inch in 24 hours.

Assuming in both calculations that the greatest power is consumed in producing the smallest quantity in total of the finest powder, then

$$424 \text{ lbs. falling } 0{\cdot}5653 \text{ feet } \times 52{\cdot}143 = 29{\cdot}479 \text{ feet per minute,}$$

$$\text{or } 29{\cdot}479 \times 1440 = 42449{\cdot}76 \text{ feet per 24 hours,}$$

which is 424 lbs. $\times 42449{\cdot}76 = 17998698{\cdot}24$ foot-pounds, being the work to crush 6736 lbs. of quartz,

$$\text{or } \frac{17998698{\cdot}24}{6736} = 2672{\cdot}01 \text{ foot-pounds expended per pound of quartz,}$$

$$\text{or } 2672 \times 165{\cdot}431 = 442031{\cdot}632 \text{ foot-pounds per cubic foot of quartz;}$$

and dividing by $J=772$, $\frac{442031{\cdot}632}{772} = 572^\circ{\cdot}58$ Fahr. in 1 lb. of water as the equivalent of the crushing work of one cubic foot of quartz-powder of $\frac{1}{66{\cdot}143}$ of a square inch fineness.

We thus come to this: $\frac{1}{167}$ of a square inch, allowing say $\frac{1}{50}$ inch for the diameter of the wires of the wire gauze or screen, was about $\frac{1}{18}$ inch average diameter of the largest fragments; $\frac{1}{116{\cdot}571}$ of a square inch, same allowance, was about $\frac{1}{14}$ inch average diameter of fragments; $\frac{1}{66{\cdot}143}$ of a square inch, same allowance, was about $\frac{1}{10}$ inch average diameter of fragments.

Then the proportionate foot-pounds to sizes of fragments and equivalent of heat are (omitting decimals):—

Size	$\frac{1}{18}$	$\frac{1}{14}$	$\frac{1}{10}$
Foot-pounds	6998310	1795435	442031.
Heat, degrees Fahr.	9065°	2325°	572°.

These results are valuable, from the general corroboration they afford of the correctness of the results as to crushing experimentally given in the body of this paper. The friction of the stamping-machinery is, as may be seen, excluded from our calculation; and except what small amount of power due to the fall of the "stamp-head" may be consumed in splashing about the water constantly flowing over the crushing quartz, there is almost no power consumed except directly in the pulverization of the quartz.

C. *Work of crushing, derived from experiments (Phil. Trans.* 1862) *on Holyhead Rocks.*

The *hardest* quartz rock (sp. gr. 2·656).

Across lamination crushed with 37,000 lbs. on the square inch.
Parallel with lamination . . 20,000
2)57,000
Mean of quartz both ways . 28,500 lbs.

Then, on a cubic foot,

$$144 \times 28{,}500 = 4104000 \text{ lbs. to crush;}$$

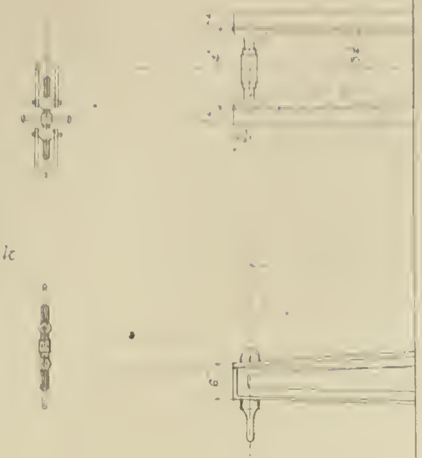
and supposing the cube all crushed to powder and dissipated laterally, then this pressure would have descended 1 foot; we therefore have the work of crushing the 1 foot cube

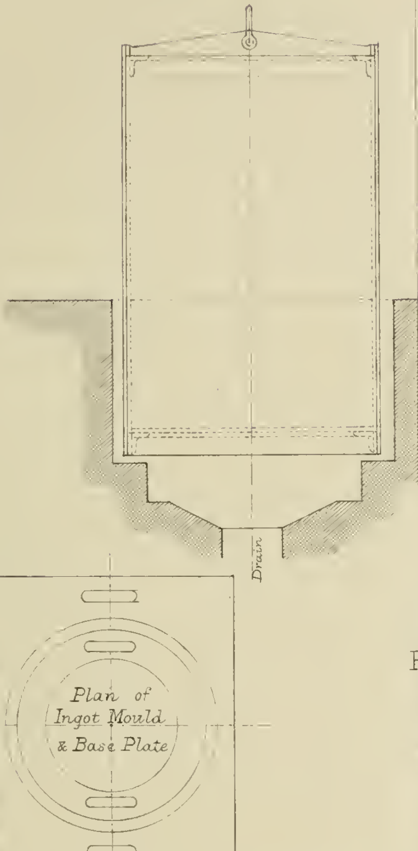
$$=4104000 \times 1 = 4104000 \text{ lbs.},$$

and

$$\frac{4104000}{772} = 5316^{\circ}\cdot 06 \text{ Fahr. in 1 lb. of water.}$$

This result, however, is below the truth, as the quartz rock was not crushed absolutely to powder.





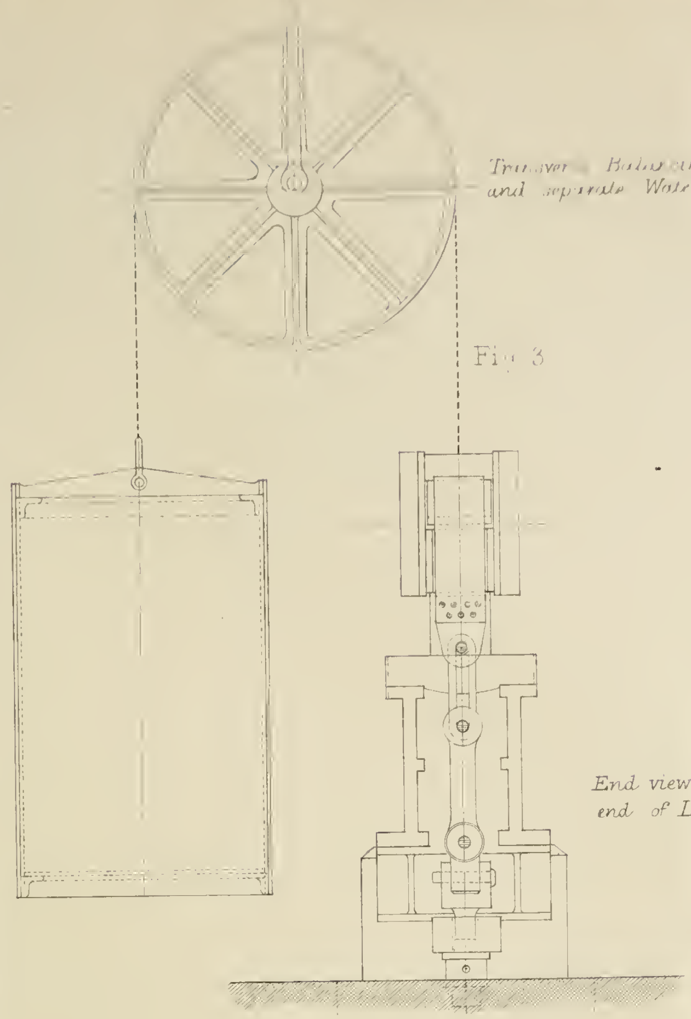
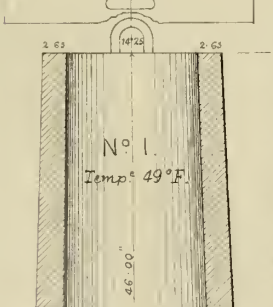
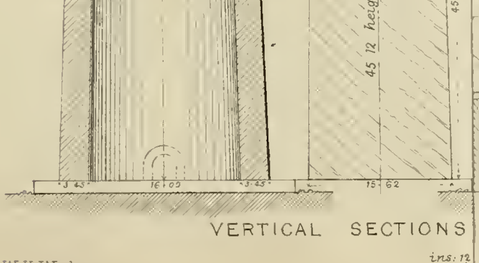

Transverse Balancing Pulley and separate Water balance
End view of Shackle-end of Lever.

Fig 3





VERTICAL SECTIONS

ins: 12

W H Wesley sc

F

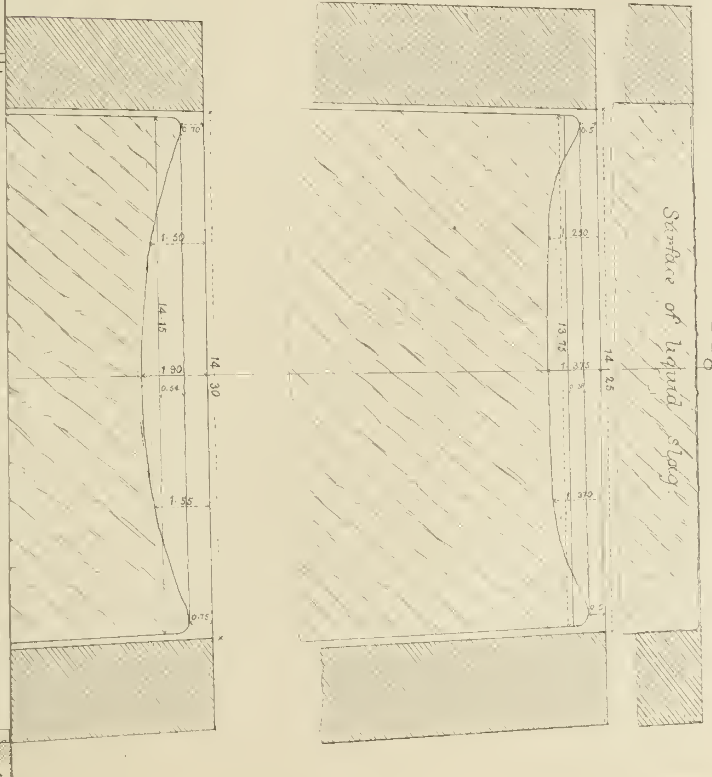
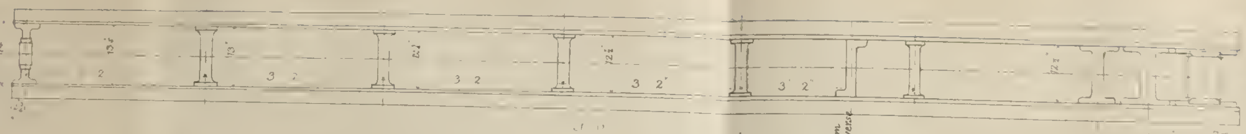


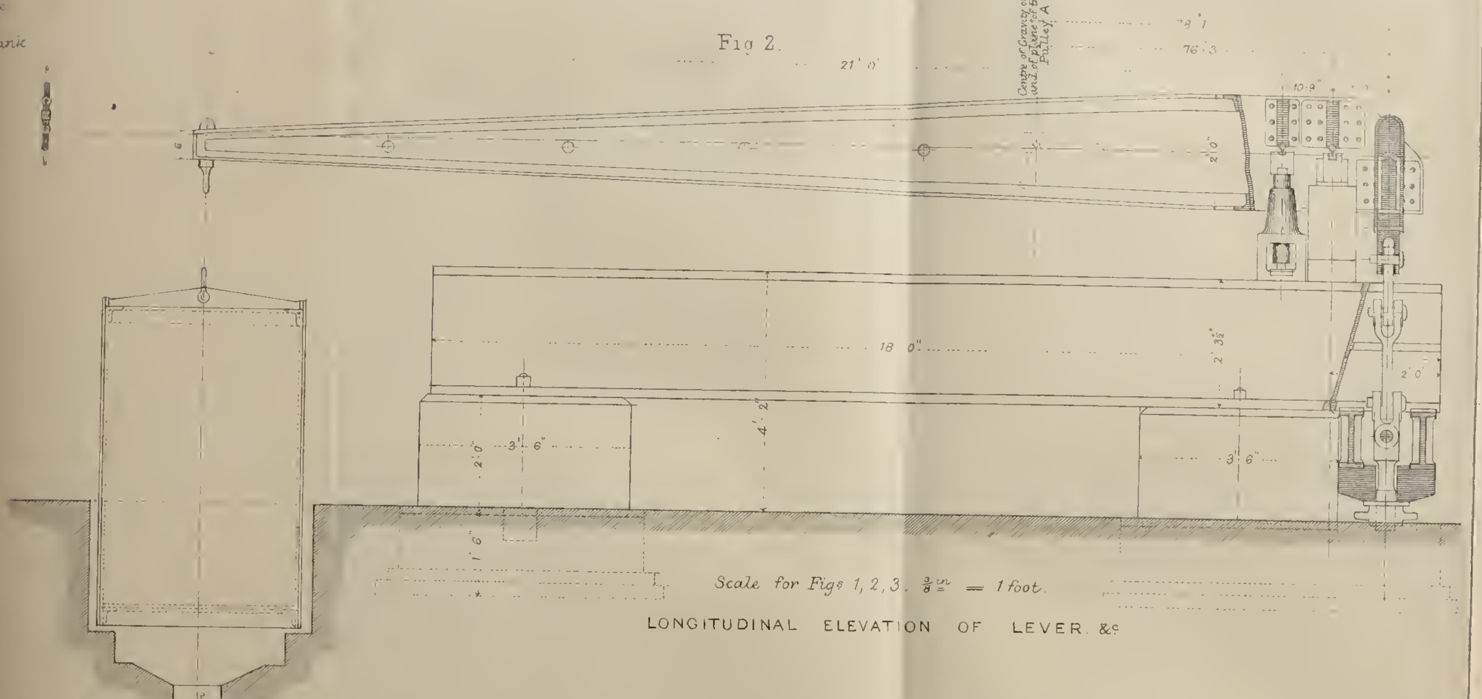
Fig. 5.

Fig. 1.



PLAN OF GIRDERS UNDER LEVER

Fig. 2.



Scale for Figs 1, 2, 3. 3/8 in = 1 foot.

LONGITUDINAL ELEVATION OF LEVER &c.

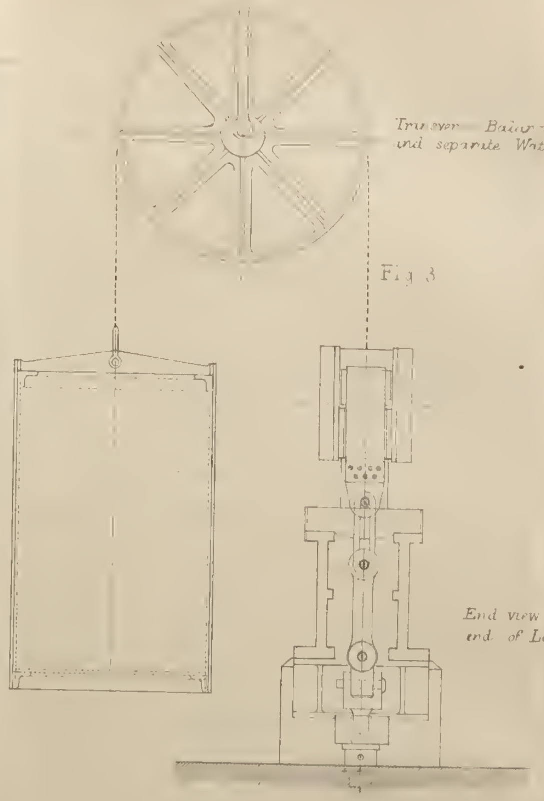
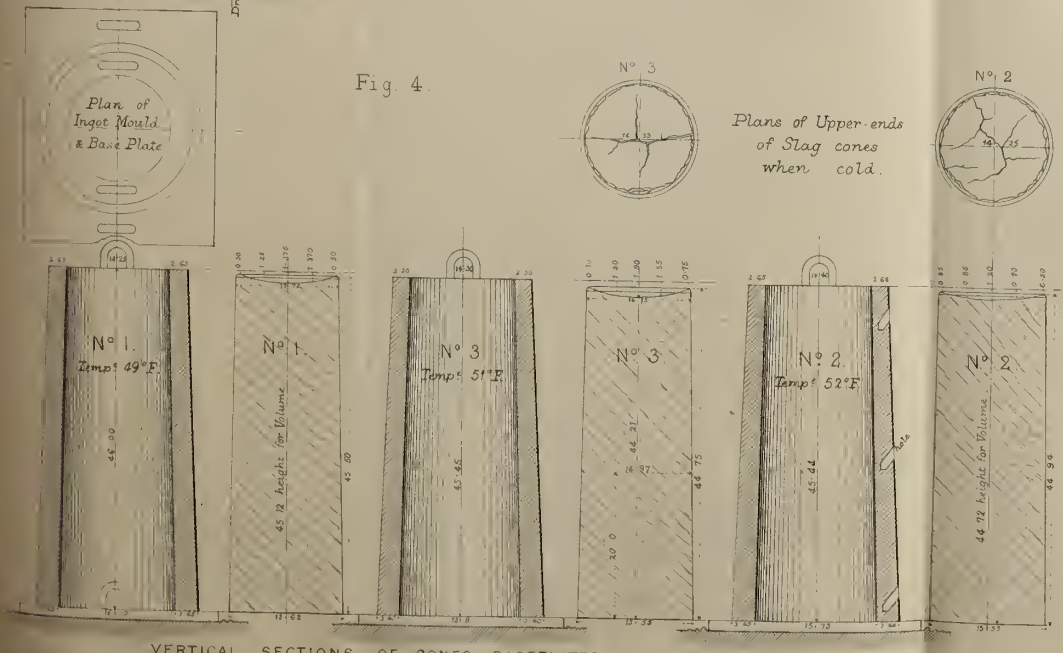

Transverse Balancing Pulley, and separate Water balance.
Fig. 3.
End view of Shackle end of Lever.

Fig. 4.



VERTICAL SECTIONS OF CONES, BASEPLATES & RESPECTIVE SLAG CASTINGS

ins. 12 9 6 3 0 1 2 3 feet
SCALE

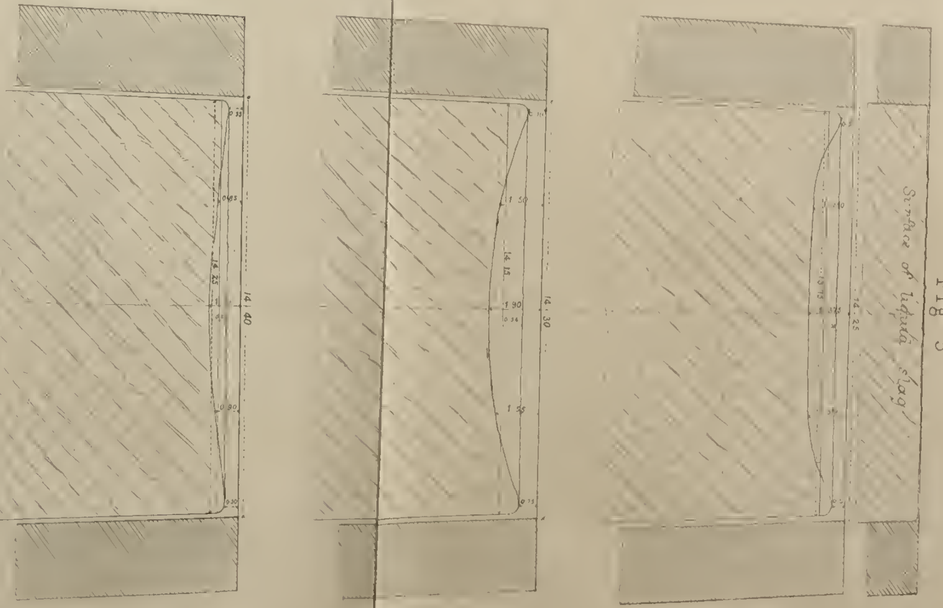
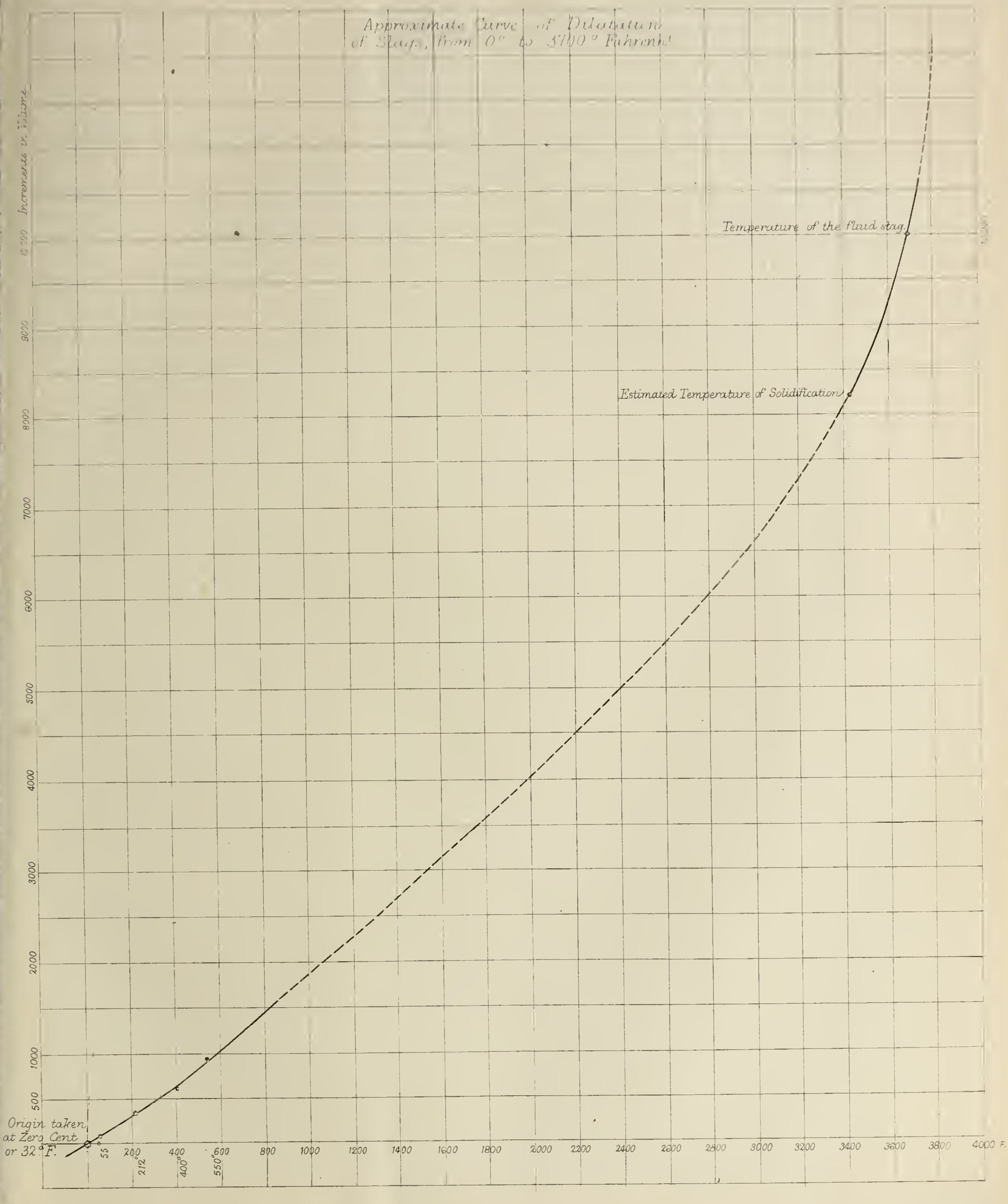


Fig. 5

Upper Surfaces of Slag cones when cold

Fig. 14.



Approximate Curve of Dilatation of Slag, from 0° to 3700° Fahrenht.

W. H. Wesley lith

W West & Cº imp.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

IV. *On Curvature and Orthogonal Surfaces.* *By* A. Cayley, *LL.D., F.R.S., Sadlerian Professor of Mathematics in the University of Cambridge.*

Received December 27, 1872,—Read February 13, 1873.

The principal object of the present Memoir is the establishment of the partial differential equation of the third order satisfied by the parameter of a family of surfaces belonging to a triple orthogonal system. It was first remarked by Bouquet that a given family of surfaces does not in general belong to an orthogonal system, but that (in order to its doing so) a condition must be satisfied; it was afterwards shown by Serret that the condition is that the parameter, considered as a function of the coordinates, must satisfy a partial differential equation of the third order: this equation was not obtained by him or the other French geometers engaged on the subject, although methods of obtaining it, essentially equivalent but differing in form, were given by Darboux and Levy; the last-named writer even found a particular form of the equation, viz. what the general equation becomes on writing therein $X=0$, $Y=0$ (X, Y, Z the first derived functions, or quantities proportional to the cosine-inclinations of the normal). Using Levy's method, I obtained the general equation, and communicated it to the French Academy. My result was, however, of a very complicated form, owing, as I afterwards discovered, to its being encumbered with the extraneous factor $X^2+Y^2+Z^2$; I succeeded, by some difficult reductions, in getting rid of this factor, and so obtaining the equation in the form given in the present memoir, viz.

$$((A), (B), (C), (F), (G), (H)\mathord{)\!(}\delta a, \delta b, \delta c, 2\delta f, 2\delta g, 2\delta h)$$

$$-2((A), (B), (C), (F), (G), (H)\mathord{)\!(}\bar{a}, \bar{b}, \bar{c}, 2\bar{f}, 2\bar{g}, 2\bar{h})=0:$$

but the method was an inconvenient one, and I was led to reconsider the question. The present investigation, although the analytical transformations are very long, is in theory extremely simple: I consider a given surface, and at each point thereof take along the normal an infinitesimal length ϱ (not a constant, but an arbitrary function of the coordinates), the extremities of these distances forming a new surface, say the vicinal surface; and the points on the same normal being considered as corresponding points, say this is the conormal correspondence of vicinal surfaces. In order that the two surfaces may belong to an orthogonal system, it is necessary and sufficient that at each point of the given surface the principal tangents (tangents to the curves of curvature) shall correspond to the principal tangents at the corresponding point of the vicinal surface; and the condition for this is that ϱ shall satisfy a partial differential equation of the second order,

$$((A), (B), (C), (F), (G), (H)\mathord{)\!(}d_x, d_y, d_z)^2\varrho=0,$$

where the coefficients depend on the first and second differential coefficients of U, if $U=0$ is the equation of the given surface. Now, considering the given surface as belonging to a family, or writing its equation in the form $r-r(x, y, z)=0$ (the last r a functional symbol), the condition in order that the vicinal surface shall belong to this family, or say that it shall coincide with the surface $r+\delta r-r(x, y, z)=0$, is $\rho=\frac{\delta r}{V}$, where $V=\sqrt{X^2+Y^2+Z^2}$, if X, Y, Z are the first differential coefficients of $r(x, y, z)$, that is, of the parameter r considered as a function of the coordinates; we have thus the equation

$$((A), (B), (C), (F), (G), (H)\between d_x, d_y, d_z)^2\frac{1}{V}=0,$$

viz. the coefficients being functions of the first and second differential coefficients of r, and V being a function of the first differential coefficients of r, this is in fact a relation involving the first, second, and third differential coefficients of r, or it is the partial differential equation to be satisfied by the parameter r considered as a function of the coordinates. After all reductions, this equation assumes the form previously mentioned.

On the Curvature of Surfaces. Article Nos. 1 to 21.

1. Curvature is a metrical theory having reference to the circle at infinity; each point in space may be regarded as the vertex of a cone passing through this circle, say the circular cone; a line and plane through the vertex are at right angles to each other when they are polar line and polar plane in regard to the cone; and so two lines or two planes are at right angles when they are harmonics in regard to the cone, that is, when each line lies in the polar plane, or each plane passes through the polar line of the other. A plane through the vertex meets the cone in two lines, which are the "circular lines" in the plane and through the point; a line through the vertex has through it two tangent planes, which might be called the "circular planes" of the point and through the line; but the term is hardly required. Lines in the plane and through the point, at right angles to each other, are also harmonics (polar lines) in regard to the two circular lines.

2. Consider now a surface, and any point thereof; we have at this point a tangent plane and a normal. The tangent plane meets the surface in a curve having at the point a node, and the tangents to the two branches of the curve (being of course lines in the tangent plane) are the "chief tangents" of the surface at the point.

3. The chief tangents are the intersections of the tangent plane by a quadric cone, which may be called the chief cone; but it is important to observe that this cone is not independent of the particular form under which the equation of the surface is presented. To explain this, suppose that the rational equation of the surface is $U=0$; taking ξ, η, ζ as current coordinates measured from the point as origin, the equation of the chief cone is $(\xi\partial_x+\eta\partial_y+\zeta\partial_z)^2U=0$, where x, y, z denote the coordinates of the point. But it is in the sequel necessary to present the equation of the surface in a different manner; say

we have an equation between the cordinates (x, y, z) and a parameter r (r being therefore in general an irrational function of x, y, z), which, when $r=r_1$, reduces itself to $U=0$: we have then $r=r_1$ as the equation of the surface; and the corresponding equation of the chief cone is $(\xi\partial_x+\eta\partial_y+\zeta\partial_z)^2r=0$; this is not the same as the cone $(\xi\partial_x+\eta\partial_y+\zeta\partial_z)^2U=0$, although of course it intersects the tangent plane in the same two lines, viz. the chief lines; and so in general there is a distinct chief cone corresponding to each form of the equation of the surface. But adopting a definite form of equation, we have a definite chief cone intersecting the tangent plane in the chief tangents.

4. Observe that the equations $U=0$, $r=r_1$, although each relating to one and the same surface, serve to represent this surface, and that in different ways, as belonging to a family of surfaces, viz. one of these is the family $U=$const., and the other the family $r=$const. In order to represent a given surface as belonging to a certain family, we need the irrational form of equation; thus r denoting the irrational function of x, y, z determined by the equation $\frac{x^2}{a+r}+\frac{y^2}{b+r}+\frac{z^2}{c+r}=1$, we have $r=0$ as the equation of the ellipsoid $\frac{x^2}{a}+\frac{y^2}{b}+\frac{z^2}{c}=1$, considered as belonging to a family of confocal quadrics.

5. Although at first sight presenting some difficulty, it is convenient to use the same letter r to denote the parameter considered as a function of the coordinates, and the special value of the parameter; thus in general the equation of a surface may be written $r(x, y, z)-r=0$ (in which form the first r may be regarded as a functional symbol), or simply $r-r=0$, viz. the first r here denotes the given function of (x, y, z), and the second r the particular value of the parameter.

6. By what precedes we have through the point and in the tangent plane two circular lines, the intersections of the tangent plane by the circular cone having the point for its vertex.

We have also through the point and in the tangent plane two other lines, termed the principal tangents, viz. the definition of these is that they are the double (or sibiconjugate) lines of the involution formed by the circular lines and the chief tangents, or, what is the same thing, they are the bisectors (and as such at right angles to each other) of the angles formed by the chief tangents.

7. The principal tangents may also be considered as the intersections of the tangent plane by a quadric cone, called the principal cone; this being a cone constructed by means of the circular cone and the chief cone, and thus depending on the particular chief cone, that is, on the form of the equation of the surface. The definition is that the principal cone is the locus of a line (through the point), such that the line itself, the perpendicular (or harmonic in regard to the circular cone) of the polar plane of the line in regard to the chief cone, and the normal of the surface are *in plano*.

8. Analytically, taking, as before, (x, y, z) for the coordinates of the point, and u, v, w as current coordinates measured from the point as origin, then the equation of the circular cone is $u^2+v^2+w^2=0$; and taking $Xu+Yv+Zw=0$ for the equation of the tangent

plane, and $(a, b, c, f, g, h \between u, v, w)^2=0$ for that of the chief cone, then, if the line be $u : v : w = \xi : \eta : \zeta$, we have

$$(a, \ldots \between \xi, \eta, \zeta \between u, v, w)=0$$

for the equation of the polar plane, and thence

$$u : v : w = a\xi+h\eta+g\zeta : h\xi+b\eta+f\zeta : g\xi+f\eta+c\zeta$$

for those of the perpendicular, or harmonic in regard to the circular cone; also for the normal $u, v, w = X : Y : Z$; whence, if the three lines are *in plano*, we have

$$\begin{vmatrix} \xi\ , & \eta\ , & \zeta \\ a\xi+h\eta+g\zeta, & h\xi+b\eta+f\zeta, & g\xi+f\zeta+c\zeta \\ X\ , & Y\ , & Z \end{vmatrix}=0$$

as the equation of the principal cone. This is in the sequel written, for shortness, as

$$\begin{vmatrix} \xi, & \eta, & \zeta \\ \delta\xi, & \delta\eta, & \delta\zeta \\ X, & Y, & Z \end{vmatrix}=0.$$

9. Consider any point P′, not in general on the surface, in the neighbourhood of the point on the surface, say P; then the point P′ has in regard to the surface a polar plane, which plane, however, is dependent on the particular form of equation—viz. x', y', z' being the coordinates of P′, and U′ the same function of these that U is of x, y, z, then the form $U=0$ of the equation of the surface gives for P′ the polar plane $(ud_{x'}+vd_{y'}+wd_{z'})U'=0$; and we may through P′ draw hereto a perpendicular (or harmonic in regard to the circular cone), say this is the normal line of P′. Then for points P′ in the neighbourhood of P, when these are such that their normal lines meet the normal at P, the locus of P′ is the before-mentioned principal cone. The analytical investigation presents no difficulty.

10. Taking P′ on the surface, the normal line of P′ becomes the normal at a consecutive point P′ of the surface (being now a line independent of the particular form of equation), and this normal meets the normal at P; that is, we have the principal cone meeting the tangent plane in two lines, the principal tangents, such that at a consecutive point P′ on either of these the normal meets the normal at P; viz. we have the principal tangents as the tangents of the two curves of curvature through the point P.

The plane through the normal and a principal tangent is termed a principal plane; we have thus at the point of the surface two principal planes, forming with the tangent plane an orthogonal triad of planes.

11. I proceed to further develop the theory, commencing with the following lemma:—

Lemma. Given the line $Xu+Yv+Zw=0$, and conic

$$(a, b, c, f, g, h \between u, v, w)^2=0,$$

then, to determine the coordinates (u_1, v_1, w_1), (u_2, v_2, w_2) of the points of intersection of the line and conic, we have

$$\begin{aligned}&(a, \ldots \between Y\zeta - Z\eta,\ Z\xi - X\zeta,\ X\eta - Y\xi)^2 \\ &\qquad = (\xi u_1 + \eta v_1 + \zeta w_1)(\xi u_2 + \eta v_2 + \zeta w_2),\end{aligned}$$

or, what is the same thing, we have

$$(a, \ldots \between Y\zeta - Z\eta,\ Z\xi - X\zeta,\ X\eta - Y\xi)^2 = 0$$

as the equation, in line coordinates, of the two points of intersection. The proof is obvious.

12. Making the equations refer to a plane and a cone, and writing throughout ξ, η, ζ as current point coordinates, the theorem is:—

Given the plane $X\xi + Y\eta + Z\zeta = 0$, and cone

$$(a, b, c, f, g, h \between \xi, \eta, \zeta)^2 = 0\ ;$$

then, to determine the lines of intersection of the plane and cone, we have

$$(a, \ldots \between Y\zeta - Z\eta,\ Z\xi - X\zeta,\ X\eta - Y\xi)^2 = 0$$

as the equation of the pair of planes at right angles to the two lines respectively.

13. Denoting the coefficients by (a), (b), &c., that is, writing

$$\begin{aligned}&(a, \ldots \between Y\zeta - Z\eta,\ Z\xi - X\zeta,\ X\eta - Y\xi)^2 \\ &\qquad = ((a), (b), (c), (f), (g), (h) \between \xi, \eta, \zeta)^2,\end{aligned}$$

the values of these are

$$\begin{aligned}(a) &= bZ^2 + cY^2 - 2fYZ, \\ (b) &= cX^2 + aZ^2 - 2gZX, \\ (c) &= aY^2 + bX^2 - 2hXY, \\ (f) &= -aYZ - fX^2 + gXY + hXZ, \\ (g) &= -bZX + fYX - gY^2 + hYZ, \\ (h) &= -cXY + fZX + gZY - hZ^2.\end{aligned}$$

We have the following identities:—

$$\begin{aligned}(a)X + (h)\,Y + (g)\,Z &= 0, \\ (h)X + (b)\,Y + (f)Z &= 0, \\ (g)X + (f)Y + (c)\,Z &= 0,\end{aligned}$$

$$((b)(c) - (f)^2, \ldots, (g)(h) - (a)(f), \ldots) = -(X^2, Y^2, Z^2, YZ, ZX, XY)\phi,$$

that is, $(b)(c) - (f)^2 = -X^2\phi$ &c., where

$$\phi = (bc - f^2, \ldots gh - af, \ldots \between X, Y, Z)^2.$$

Writing also

$$aX+hY+gZ,\ hX+bY+fZ,\ gX+fY+cZ=\delta X,\ \delta Y,\ \delta Z,$$

and $X^2+Y^2+Z^2=V^2$; also $a+b+c=\omega$, then

$$\begin{aligned}
(a) &=(b+c)V^2-\omega X^2 +X\delta X-Y\delta Y-Z\delta Z,\\
(b) &=(c+a)V^2-\omega Y^2 -X\delta X+Y\delta Y-Z\delta Z,\\
(c) &=(a+b)V^2-\omega Z^2 -X\delta X-Y\delta Y+Z\delta Z,\\
(f) &=-fV^2 \quad -\omega YZ+Y\delta Z +Z\delta Y,\\
(g) &=-gV^2 \quad -\omega ZX+Z\delta X +X\delta Z,\\
(h) &=-hV^2 \quad -\omega YZ+X\delta Y+Y\delta X.
\end{aligned}$$

14. I give also the following lemma:—

Lemma. The condition in order that the plane $X\xi+Y\eta+Z\zeta=0$ may meet the cones

$$(A, B, C, F, G, H\between \xi, \eta, \zeta)^2=0,$$
$$(A', B', C', F', G', H'\between \xi, \eta, \zeta)^2=0$$

in two pairs of lines harmonically related to each other, is

$$(BC'+B'C-2FF', \ldots, GH'+G'H-AF'-A'F, \ldots \between X, Y, Z)^2=0.$$

Writing here

$$(A, \ldots \between Y\zeta-Z\eta,\ Z\xi-X\zeta,\ X\eta-Y\xi)^2$$
$$=((A), (B), (C), (F), (G), (H)\between \xi, \eta, \zeta)^2,$$

that is, $(A)=BZ^2+CY^2-2FYZ$, &c., the condition may be written

$$(A)A'+(B)B'+(C)C'+2(F)F'+2(G)G'+2(H)H'=0,$$

or say

$$((A), \ldots \between A', \ldots)=0;$$

and we may, it is clear, interchange the accented and unaccented letters respectively.

15. I take $r-r=0$ for the equation of a surface, X, Y, Z for the first derived functions of r, (a, b, c, f, g, h) for the second derived functions. The equation of the tangent plane at the point (x, y, z), taking ξ, η, ζ as current coordinates measured from this point, is

$$X\xi+Y\eta+Z\zeta=0;$$

the equation of the chief cone in regard to this form of the equation of the surface is

$$(a, b, c, f, g, h\between \xi, \eta, \zeta)^2=0,$$

and the equation of the circular cone is $\xi^2+\eta^2+\zeta^2=0$, or, what is the same thing,

$$(1, 1, 1, 0, 0, 0\between \xi, \eta, \zeta)^2=0.$$

Imagine a quadric cone,

$$(A, B, C, F, G, H\between \xi, \eta, \zeta)^2=0,$$

such that it meets the tangent plane in the sibiconjugate lines of the involution formed by the intersections of the tangent plane by the chief cone and the circular cone respectively; that is, in a pair of lines harmonically related to the intersections with the chief cone, and also to the intersections with the circular cone; the conditions are

$$((\mathrm{A}), \ldots \between a, \ldots)=0,$$

and

$$(\mathrm{A})+(\mathrm{B})+(\mathrm{C})=0,$$

viz. if only these two conditions are satisfied the cone will intersect the tangent plane in the two principal tangents.

16. The principal cone, writing, for shortness,

$$a\xi+h\eta+g\zeta,\ h\xi+b\eta+f\zeta,\ g\xi+f\eta+c\zeta=\delta\xi,\ \delta\eta,\ \delta\zeta,$$

was before taken to be the cone

$$\begin{vmatrix} \xi, & \eta, & \zeta \\ \delta\xi, & \delta\eta, & \delta\zeta \\ \mathrm{X}, & \mathrm{Y}, & \mathrm{Z} \end{vmatrix}=0.$$

Representing this equation by

$$\tfrac{1}{2}(\mathrm{A}, \mathrm{B}, \mathrm{C}, \mathrm{F}, \mathrm{G}, \mathrm{H} \between \xi, \eta, \zeta)^2=0,$$

the expressions of the coefficients are

$$\begin{aligned}
\mathrm{A}&=2h\mathrm{Z}-2g\mathrm{Y},\\
\mathrm{B}&=2f\mathrm{X}-2h\mathrm{Z},\\
\mathrm{C}&=2g\mathrm{Y}-2f\mathrm{X},\\
\mathrm{F}&=h\mathrm{Y}-g\mathrm{Z}-(b-c)\mathrm{X},\\
\mathrm{G}&=f\mathrm{Z}-h\mathrm{X}-(c-a)\mathrm{Y},\\
\mathrm{H}&=g\mathrm{X}-f\mathrm{Y}-(a-b)\mathrm{Z}.
\end{aligned}$$

These values give

$$\begin{aligned}
\mathrm{AX}+\mathrm{HY}+\mathrm{GZ}&=\mathrm{Z}\delta\mathrm{Y}-\mathrm{Y}\delta\mathrm{Z},\\
\mathrm{HX}+\mathrm{BY}+\mathrm{FZ}&=\mathrm{X}\delta\mathrm{Z}-\mathrm{Z}\delta\mathrm{X},\\
\mathrm{GX}+\mathrm{FY}+\mathrm{CZ}&=\mathrm{Y}\delta\mathrm{X}-\mathrm{X}\delta\mathrm{Y};
\end{aligned}$$

whence also

$$(\mathrm{A}, \ldots \between \mathrm{X}, \mathrm{Y}, \mathrm{Z})^2=0,$$

as is, in fact, at once obvious from the determinant-form; and also

$$\mathrm{A}+\mathrm{B}+\mathrm{C}=0.$$

17. Writing, for shortness,

$$(\overline{a}, \overline{b}, \overline{c}, \overline{f}, \overline{g}, \overline{h})=(bc-f^2, ca-g^2, ab-h^2, gh-af, hf-bg, fg-ch),$$

we find

$$\begin{aligned}
\mathrm{A}a+\mathrm{H}h+\mathrm{G}g&=\omega(h\mathrm{Z}-g\mathrm{Y})+\overline{h}\mathrm{Z}-\overline{g}\mathrm{Y},\\
\mathrm{H}h+\mathrm{B}b+\mathrm{F}f&=\omega(f\mathrm{X}-h\mathrm{Z})+\overline{f}\mathrm{X}-\overline{h}\mathrm{Z},\\
\mathrm{G}g+\mathrm{F}f+\mathrm{C}c&=\omega(g\mathrm{Y}-f\mathrm{X})+\overline{g}\mathrm{Y}-\overline{f}\mathrm{X};
\end{aligned}$$

whence

$$(\mathrm{A}, \ldots \between a, \ldots) = 0.$$

18. By what precedes, we have

$$((\mathrm{A}), \ldots \between \xi, \eta, \zeta)^2 = 0$$

for the equation of the two principal planes, where the coefficients (A), (B), &c. are functions of A, B, &c. and of X, Y, Z, as mentioned above. These coefficients satisfy of course the several relations similar to those satisfied by (a), (b), &c., and other relations dependent on the expressions of A, B, &c. in terms of a, b, &c. and X, Y, Z.

19. Proceeding to consider the coefficients (A), (B), &c., we have then

$$(\mathrm{A}) + (\mathrm{B}) + (\mathrm{C}) = (\mathrm{A} + \mathrm{B} + \mathrm{C})\mathrm{V}^2 - (\mathrm{A}, \ldots \between \mathrm{X}, \mathrm{Y}, \mathrm{Z})^2,$$

that is

$$(\mathrm{A}) + (\mathrm{B}) + (\mathrm{C}) = 0.$$

Observing the relation $\mathrm{A}+\mathrm{B}+\mathrm{C}=0$, the equations analogous to

$(a) = (b+c)\mathrm{V}^2 - (a+b+c)\mathrm{X}^2 + \&\mathrm{c}.$, are $(\mathrm{A}) = -\mathrm{AV}^2 + \mathrm{X}\delta'\mathrm{X} - \mathrm{Y}\delta'\mathrm{Y} - \mathrm{Z}\delta'\mathrm{Z}$, &c.

if for a moment we write $\delta'\mathrm{X}$, $\delta'\mathrm{Y}$, $\delta'\mathrm{Z}$ to denote the functions

$$\mathrm{AX} + \mathrm{HY} + \mathrm{GZ},\ \mathrm{HX} + \mathrm{BY} + \mathrm{FZ},\ \mathrm{GX} + \mathrm{FY} + \mathrm{CZ}.$$

But, from the above values, $\mathrm{X}\delta'\mathrm{X} + \mathrm{Y}\delta'\mathrm{Y} + \mathrm{Z}\delta'\mathrm{Z} = 0$, or the equation is $(\mathrm{A}) = -\mathrm{AV}^2 + 2\mathrm{X}\delta'\mathrm{X}$, that is $= -\mathrm{AV}^2 + 2\mathrm{X}(\mathrm{Z}\delta\mathrm{Y} - \mathrm{Y}\delta\mathrm{Z})$. The equation for (F) is $(\mathrm{F}) = -\mathrm{FV}^2 + \mathrm{Y}\delta'\mathrm{Z} + \mathrm{Z}\delta'\mathrm{Y}$, where $\mathrm{Y}\delta'\mathrm{Z} + \mathrm{Z}\delta'\mathrm{Y}$ is $= \mathrm{Y}(\mathrm{Y}\delta\mathrm{X} - \mathrm{X}\delta\mathrm{Y}) + \mathrm{Z}(\mathrm{X}\delta\mathrm{Z} - \mathrm{Z}\delta\mathrm{X})$, viz. this is

$$= (\mathrm{Y}^2 - \mathrm{Z}^2)\delta\mathrm{X} - \mathrm{XY}\delta\mathrm{Y} + \mathrm{XZ}\delta\mathrm{Z}.$$

We have thus the system of equations

$$\begin{array}{llll}
(\mathrm{A}) = -\mathrm{AV}^2 & . & +2\mathrm{XZ}\delta\mathrm{Y} & -2\mathrm{XY}\delta\mathrm{Z}, \\
(\mathrm{B}) = -\mathrm{BV}^2 & -2\mathrm{YZ}\delta\mathrm{X} & . & +2\mathrm{XY}\delta\mathrm{Z}, \\
(\mathrm{C}) = -\mathrm{CV}^2 & +2\mathrm{YZ}\delta\mathrm{X} & -2\mathrm{XZ}\delta\mathrm{Y} & . \\
(\mathrm{F}) = -\mathrm{FV}^2 & +(\mathrm{Y}^2-\mathrm{Z}^2)\delta\mathrm{X} & -\mathrm{XY}\delta\mathrm{Y} & +\mathrm{XZ}\delta\mathrm{Z}, \\
(\mathrm{G}) = -\mathrm{GV}^2 & +\mathrm{XY}\delta\mathrm{X} & +(\mathrm{Z}^2-\mathrm{X}^2)\delta\mathrm{Y} & -\mathrm{YZ}\delta\mathrm{Z}, \\
(\mathrm{H}) = -\mathrm{HV}^2 & -\mathrm{XZ}\delta\mathrm{X} & +\mathrm{YZ}\delta\mathrm{Y} & +(\mathrm{X}^2-\mathrm{Y}^2)\delta\mathrm{Z}.
\end{array}$$

20. We hence find

$$\begin{aligned}
(\mathrm{A})a + (\mathrm{H})h + (\mathrm{G})g &= -(\mathrm{A}a + \mathrm{H}h + \mathrm{G}g)\mathrm{V}^2 + (\mathrm{Z}\delta\mathrm{Y} - \mathrm{Y}\delta\mathrm{Z})\delta\mathrm{X} + \mathrm{XP}, \\
(\mathrm{H})h + (\mathrm{B})b + (\mathrm{F})f &= -(\mathrm{H}h + \mathrm{B}b + \mathrm{F}f)\mathrm{V}^2 + (\mathrm{X}\delta\mathrm{Z} - \mathrm{Z}\delta\mathrm{X})\delta\mathrm{Y} + \mathrm{YQ}, \\
(\mathrm{G})g + (\mathrm{F})f + (\mathrm{C})c &= -(\mathrm{G}g + \mathrm{F}f + \mathrm{C}c)\mathrm{V}^2 + (\mathrm{Y}\delta\mathrm{X} - \mathrm{X}\delta\mathrm{Y})\delta\mathrm{Z} + \mathrm{ZR},
\end{aligned}$$

if, for shortness,

$$\begin{aligned}
\mathrm{P} &= (g\mathrm{Y} - h\mathrm{Z})\delta\mathrm{X} + (a\mathrm{Z} - g\mathrm{X})\delta\mathrm{Y} + (h\mathrm{X} - a\mathrm{Y})\delta\mathrm{Z}, \\
\mathrm{Q} &= (f\mathrm{Y} - b\mathrm{Z})\delta\mathrm{X} + (h\mathrm{Z} - f\mathrm{X})\delta\mathrm{Y} + (b\mathrm{X} - h\mathrm{Y})\delta\mathrm{Z}, \\
\mathrm{R} &= (c\mathrm{Y} - f\mathrm{Z})\delta\mathrm{X} + (g\mathrm{Z} - c\mathrm{X})\delta\mathrm{Y} + (f\mathrm{X} - g\mathrm{Y})\delta\mathrm{Z}.
\end{aligned}$$

Forming the sum $\mathrm{PX}+\mathrm{QY}+\mathrm{RZ}$, the coefficient of $\delta\mathrm{X}$ is found to be

$$=-\mathrm{Z}(h\mathrm{X}+b\mathrm{Y}+f\mathrm{Z})+\mathrm{Y}(g\mathrm{X}+f\mathrm{Y}+c\mathrm{Z}),\ =-\mathrm{Z}\delta\mathrm{Y}+\mathrm{Y}\delta\mathrm{Z};$$

hence the whole is

$$=\delta\mathrm{X}(\mathrm{Y}\delta\mathrm{Z}-\mathrm{Z}\delta\mathrm{Y})+\delta\mathrm{Y}(\mathrm{Z}\delta\mathrm{X}-\mathrm{X}\delta\mathrm{Z})+\delta\mathrm{Z}(\mathrm{X}\delta\mathrm{Y}-\mathrm{Y}\delta\mathrm{X}),\ \text{which is }=0,\ \text{that is,}$$

$$\mathrm{PX}+\mathrm{QY}+\mathrm{RZ}=0.$$

21. Hence, adding, we find

$$((\mathrm{A}),\ldots)(a,\ldots)=0;$$

viz. in this and the before-mentioned equation

$$(\mathrm{A})+(\mathrm{B})+(\mathrm{C})=0$$

we have the *à posteriori* verification that the cone $(\mathrm{A},\ldots)(\xi,\eta,\zeta)^2=0$ cuts the tangent plane in the double lines of the involution.

In what precedes I have given only those relations between the several sets of quantities a, $\bar{a}$, (a), A, (A), &c. which have been required for establishing the results last obtained; but there are various other relations required in the sequel, and which will be obtained as they are wanted.

The Conormal Correspondence of Vicinal Surfaces. Article Nos. 22 to 35.

22. We consider a surface $\mathrm{U}=0$ (or $r=r$), and at each point P thereof measure along the normal an infinitesimal length ϱ, dependent on the position of the point P (that is, ϱ is a function of x, y, z). We have thus a point P′, the coordinates of which are

$$x', y', z'=x+\varrho\alpha,\ y+\varrho\beta,\ z+\varrho\gamma,$$

where α, β, γ are the cosine-inclinations of the normal, that is,

$$\alpha, \beta, \gamma=\frac{\mathrm{X}}{\mathrm{V}}, \frac{\mathrm{Y}}{\mathrm{V}}, \frac{\mathrm{Z}}{\mathrm{V}},\ \text{if } \mathrm{V}=\sqrt{\mathrm{X}^2+\mathrm{Y}^2+\mathrm{Z}^2};$$

the locus of P′ is of course a surface, say the vicinal surface, and we require to find the direction of the normal at P′, or, what is the same thing, the differential equation $\mathrm{X}'dx'+\mathrm{Y}'dy'+\mathrm{Z}'dz'$ of the surface. We have

$$\begin{aligned}
dx'&=(1+d_x\varrho\alpha)\,dx+ & d_y\varrho\alpha\,.\,dy+ & & d_z\varrho\alpha\,.\,dz,\\
dy'&=\quad d_x\varrho\beta\,.\,dx+ & (1+d_y\varrho\beta)\,dy+ & & d_z\varrho\beta\,.\,dz,\\
dz'&=\quad d_x\varrho\gamma\ \ dx+ & d_y\varrho\gamma\,.\,dy+ & & (1+d_z\varrho\gamma)\,dz,\\
0\ &=\quad \mathrm{X}\ \ dx+ & \mathrm{Y}\ \ dy+ & & \mathrm{Z}\ \ dz;
\end{aligned}$$

whence, eliminating dx, dy, dz, we have between dx', dy', dz' a linear equation, the coefficients of which may be taken to be X′, Y′, Z′. Taking these only as far as the first power of ϱ, we have

$$\mathrm{X}'=\mathrm{X}(1+d_y\varrho\beta+d_z\varrho\gamma)-\mathrm{Y}d_x\varrho\beta-\mathrm{Z}d_x\varrho\gamma,$$

or, what is the same thing,

$$X'=X(1+d_x\varrho\alpha+d_y\varrho\beta+d_z\varrho\gamma)-Xd_x\varrho\alpha-Yd_x\varrho\beta-Zd_x\varrho\gamma,$$

with the like expressions for Y' and Z'. I proceed to reduce these. The formula for X' is

$$X'=X\{1+\varrho(d_x\alpha+d_y\beta+d_z\gamma)+\alpha d_x\varrho+\beta d_y\varrho+\gamma d_z\varrho\}$$
$$-\varrho(Xd_x\alpha+Yd_x\beta+Zd_x\gamma)-(\alpha X+\beta Y+\gamma Z)d_x\varrho.$$

23. I write, for shortness, $\delta=Xd_x+Yd_y+d_z$, whence δX, δY, $\delta Z=aX+hY+gZ$, $hX+bY+fZ$, $gX+fY+cZ$, agreeing with the former significations of δX, δY, dZ; also Vd_xV, Vd_yV, $Vd_zV=\delta X$, δY, δZ, and $V\delta V=X\delta X+Y\delta Y+Z\delta Z$. It is now easy to form the values of

$$d_x\alpha,\ d_x\beta,\ d_x\gamma, \quad \text{viz. these are } \frac{a}{V}-\frac{X\delta X}{V^3},\quad \frac{h}{V}-\frac{Y\delta X}{V^3},\quad \frac{g}{V}-\frac{Z\delta X}{V^3},$$

$$d_y\alpha,\ d_y\beta,\ d_y\gamma, \quad \frac{h}{V}-\frac{X\delta Y}{V^3},\quad \frac{b}{V}-\frac{Y\delta Y}{V^3},\quad \frac{f}{V}-\frac{Z\delta Y}{V^3},$$

$$d_z\alpha,\ d_z\beta,\ d_z\gamma, \quad \frac{g}{V}-\frac{X\delta Z}{V^3},\quad \frac{f}{V}-\frac{Y\delta Z}{V^3},\quad \frac{c}{V}-\frac{Z\delta Z}{V^8};$$

and hence

$$d_x\alpha+d_y\beta+d_z\gamma=\frac{a+b+c}{V}-\frac{\delta V}{V^2},$$

$$Xd_x\alpha+Yd_x\beta+Zd_x\gamma=\frac{\delta X}{V}-\frac{V^2}{V^3}\delta X,\ =0,$$

$$\alpha d_x\varrho+\beta d_y\varrho+\gamma d_z\varrho=\frac{1}{V}\delta\varrho,$$

$$\alpha X+\beta Y+\gamma Z\quad =V;$$

and we have

$$X'=X\left\{1+\varrho\left(\frac{a+b+c}{V}-\frac{\delta V}{V^2}\right)+\frac{1}{V}\delta\varrho\right\}-V\partial_x\varrho,$$

with the like values of Y' and Z'. But we are only concerned with the ratios $X':Y':Z'$; whence, dividing the foregoing values by the coefficient in $\{\}$, and taking the second terms only to the first order in ϱ, we have simply

$$X',\ Y',\ Z'=X-Vd_x\varrho,\ Y-Vd_y\varrho,\ Z-Vd_z\varrho.$$

24. We may investigate the condition in order that the surface x', y', z' may be the consecutive surface $r+dr=r(x, y, z)$. This will be the case of

$$r+dr=r\left(x+\varrho\frac{X}{V},\ y+\varrho\frac{Y}{V},\ z+\varrho\frac{Z}{V}\right),$$

that is, $r+dr=r+\varrho V$, or $\varrho=\frac{dr}{V}$. This value of ϱ gives $d_x\varrho=-\frac{dr}{V^2}d_xV=-\frac{\varrho}{V^2}\delta X$, and similarly $\partial_y\varrho=-\frac{\varrho}{V^2}\delta Y$, $d_z\varrho=-\frac{\varrho}{V^2}\delta Z$; whence

$$X',\ Y',\ Z'=X+\frac{\varrho}{V}\delta X,\ Y+\frac{\varrho}{V}\delta Y,\ Z+\frac{\varrho}{V}\delta Z,$$

which is as it should be, viz. these are what X, Y, Z become on substituting therein for x, y, z the values $x+\varrho\alpha$, $y+\varrho\beta$, $z+\varrho\gamma$.

25. I return to the case where ϱ is arbitrary, and I investigate the values of a, b, . . . for the point P′ on the vicinal surface; say these are a', b', &c., then we have $a'=d_{x'}\mathrm{X}'$ &c. The relation between the differentials may be written

$$\begin{aligned} dx&=(1-d_x\varrho\alpha)dx'-\quad d_y\varrho\alpha\, dy'-\quad d_z\varrho\alpha\, dz',\\ dy&=\quad -d_x\varrho\beta\, dx'+(1-d_y\varrho\beta)dy'-\quad d_z\varrho\beta\, dz',\\ dy&=\quad -d_x\varrho\gamma\, dx'-\quad d_y\varrho\gamma\, dy'+(1-d_z\varrho\gamma)dz', \end{aligned}$$

and we thence have $d_{x'}=(1-d_x\varrho\alpha)d_x-d_x\varrho\beta d_y-d_x\varrho\gamma d_z$ &c.; hence

$$\begin{aligned} a'&=\{(1-d_x\varrho\alpha)d_x-d_x\varrho\beta d_y-d_x\varrho\gamma d_z\}(\mathrm{X}-\mathrm{V}d_x\varrho)\\ &=(1-d_x\varrho\alpha)a-d_x\varrho\beta\,.\,h-d_x\varrho\gamma\,.\,g-d_x(\mathrm{V}d_x\varrho)\\ &=a-\varrho(ad_x\alpha+hd_x\beta+gd_x\gamma)\\ &\qquad-(a\alpha+h\beta+g\gamma)d_x\varrho\\ &\qquad-\frac{1}{\mathrm{V}}\delta\mathrm{X}d_x\varrho-\mathrm{V}d_x^2\varrho\,; \end{aligned}$$

and similarly, $f'=d_{y'}\mathrm{Z}'$ (or $d_{z'}\mathrm{Y}'$), that is

$$\begin{aligned} f'&=f-\varrho(gd_y\alpha+fd_y\beta+cd_y\gamma)\\ &\qquad-(g\alpha+f\beta+c\gamma)d_y\varrho\\ &\qquad-\frac{1}{\mathrm{V}}\delta\mathrm{Y}d_z\varrho-\mathrm{V}d_yd_z\varrho. \end{aligned}$$

26. Completing the reduction, we find

$$\begin{aligned} a'&=a-\varrho\left(\frac{a\omega-\bar{b}-\bar{c}}{\mathrm{V}}-\frac{(\delta\mathrm{X})^2}{\mathrm{V}^3}\right)-\frac{2}{\mathrm{V}}\delta\mathrm{X}d_x\varrho-\mathrm{V}d_x^2\varrho,\\ b'&=b-\varrho\left(\frac{b\omega-\bar{c}-\bar{a}}{\mathrm{V}}-\frac{(\delta\mathrm{Y})^2}{\mathrm{V}^3}\right)-\frac{2}{\mathrm{V}}\delta\mathrm{Y}d_y\varrho-\mathrm{V}d_y^2\varrho,\\ c'&=c-\varrho\left(\frac{c\omega-\bar{a}-\bar{b}}{\mathrm{V}}-\frac{(\delta\mathrm{Z})^2}{\mathrm{V}^3}\right)-\frac{2}{\mathrm{V}}\delta\mathrm{Z}d_z\varrho-\mathrm{V}d_z^2\varrho,\\ f'&=f-\varrho\left(\frac{\omega f+\bar{f}}{\mathrm{V}}-\frac{\delta\mathrm{Y}\delta\mathrm{Z}}{\mathrm{V}^3}\right)-\frac{1}{\mathrm{V}}(\delta\mathrm{Y}d_z\varrho+\delta\mathrm{Z}d_y\varrho)-\mathrm{V}d_yd_z\varrho,\\ g'&=g-\varrho\left(\frac{\omega g+\bar{g}}{\mathrm{V}}-\frac{\delta\mathrm{Z}\delta\mathrm{X}}{\mathrm{V}^3}\right)-\frac{1}{\mathrm{V}}(\delta\mathrm{Z}d_x\varrho+\delta\mathrm{X}d_y\varrho)-\mathrm{V}d_zd_x\varrho,\\ h'&=h-\varrho\left(\frac{\omega h+\bar{h}}{\mathrm{V}}-\frac{\delta\mathrm{X}\delta\mathrm{Y}}{\mathrm{V}^3}\right)-\frac{1}{\mathrm{V}}(\delta\mathrm{X}d_y\varrho+\delta\mathrm{Y}d_z\varrho)-\mathrm{V}d_xd_y\varrho\,; \end{aligned}$$

say these expressions are $a'=a+\Delta a$, &c.

27. Taking ξ, η, ζ for the coordinates, referred to P as origin, of a point on the given surface near to P, and ξ', η', ζ' for the coordinates, referred to P$'$ as origin, of the corresponding point on the vicinal surface, the relation between ξ', η', ζ' and ξ, η, ζ is the same as that between dx', dy', dz' and dx, dy, dz; viz. we have

$$\begin{aligned}
\xi&=\xi'(1-d_x\varrho\alpha)-d_y\varrho\alpha\,.\,\eta' \quad -d_z\varrho\alpha\,.\,\zeta',\\
\eta&=-d_x\varrho\beta\,.\,\xi' \;+(1-d_y\varrho\beta)\eta'-d_z\varrho\beta\,.\,\zeta',\\
\zeta&=-d_x\varrho\gamma\,.\,\xi' \;-d_y\varrho\gamma\,.\,\eta' \quad +(1-d_z\varrho\gamma)\zeta';
\end{aligned}$$

or, conversely,

$$\begin{aligned}
\xi'&=(1+d_x\varrho\alpha)\,\xi+ \quad d_y\varrho\alpha\,.\,\eta+d_z\varrho\alpha\,.\,\zeta,\\
\eta'&= \quad d_x\varrho\beta\,.\,\xi+(1+d_y\varrho\beta)\eta+d_z\varrho\beta\,.\,\zeta,\\
\zeta'&= \quad d_x\varrho\gamma\,.\,\xi+ \quad d_y\varrho\gamma\,.\,\eta+(1+d_z\varrho\gamma)\zeta',
\end{aligned}$$

say $\xi', \eta', \zeta'=\xi+\Delta\xi,\ \eta+\Delta\eta,\ \zeta+\Delta\zeta$; hence

$$\begin{aligned}
\mathrm{X}'\xi'+\mathrm{Y}'\eta'+\mathrm{Z}'\zeta'&=(\mathrm{X}-\mathrm{V}d_x\varrho)(\xi+\Delta\xi)+\&c.\\
&=\mathrm{X}\xi+\mathrm{Y}\eta+\mathrm{Z}\zeta\\
&\quad+\mathrm{X}\Delta\xi+\mathrm{Y}\Delta\eta+\mathrm{Z}\Delta\zeta\\
&\quad-\mathrm{V}(\xi d_x\varrho+\eta d_y\varrho+\zeta d_z\varrho),
\end{aligned}$$

where second line is

$$\begin{aligned}
&(\mathrm{X}\alpha+\mathrm{Y}\beta+\mathrm{Z}\gamma)(\xi d_x\varrho+\eta d_y\varrho+\zeta d_z\varrho)\\
&+\varrho\{(\mathrm{X}d_x\alpha+\mathrm{Y}d_x\beta+\mathrm{Z}d_x\gamma)\xi+(\mathrm{X}d_y\alpha+\mathrm{Y}d_y\beta+\mathrm{Z}d_y\gamma)\eta+(\mathrm{X}d_z\alpha+\mathrm{Y}d_z\beta+\mathrm{Z}d_z\gamma)\zeta\}.
\end{aligned}$$

But

$$\begin{aligned}
\mathrm{X}d_x\alpha+\mathrm{Y}d_x\beta+\mathrm{Z}d_x\gamma&=\frac{\delta\mathrm{X}}{\mathrm{V}}-\frac{\mathrm{V}^2}{\mathrm{V}^3}\delta\mathrm{X}=0,\\
\mathrm{X}d_y\alpha+\mathrm{Y}d_y\beta+\mathrm{Z}d_y\gamma&=0,\\
\mathrm{X}d_z\alpha+\mathrm{Y}d_z\beta+\mathrm{Z}d_z\gamma&=0,
\end{aligned}$$

or second line is $=\mathrm{V}(\xi d_x\varrho+\eta d_y\varrho+\zeta d_z\varrho)$; and we have therefore

$$\mathrm{X}'\xi'+\mathrm{Y}'\eta'+\mathrm{Z}'\zeta'=\mathrm{X}\xi+\mathrm{Y}\eta+\mathrm{Z}\zeta.$$

We require

$(\mathrm{A}', \mathrm{B}', \mathrm{C}', \mathrm{F}', \mathrm{G}', \mathrm{H}' \between \xi', \eta', \zeta')^2$; viz., to the first order in ϱ, this is

$$\begin{aligned}
&=(\mathrm{A}', \ldots \between \xi, \eta, \zeta)^2\\
&\quad+2(\mathrm{A}, \ldots \between \Delta\xi, \Delta\eta, \Delta\zeta \between \xi, \eta, \zeta).
\end{aligned}$$

28. Here second line is

$$2\{(\mathrm{A}\xi+\mathrm{H}\eta+\mathrm{G}\zeta)\Delta\xi+(\mathrm{H}\xi+\mathrm{B}\eta+\mathrm{F}\zeta)\Delta\eta+(\mathrm{G}\xi+\mathrm{F}\eta+\mathrm{C}\zeta)\Delta\zeta\};$$

but

$$A\xi+H\eta+G\zeta=Z\delta\eta-Y\delta\zeta+\begin{vmatrix} a, & h, & g \\ X, & Y, & Z \\ \xi, & \eta, & \zeta \end{vmatrix},$$

$$H\xi+B\eta+F\zeta=X\delta\zeta-Z\delta\xi+\begin{vmatrix} h, & b, & f \\ X, & Y, & Z \\ \xi, & \eta, & \zeta \end{vmatrix},$$

$$G\xi+F\eta+C\zeta=Y\delta\xi+X\delta\eta+\begin{vmatrix} g, & f, & c \\ X, & Y, & Z \\ \xi, & \eta, & \zeta \end{vmatrix},$$

whence term in { } is

$$\begin{vmatrix} \Delta\xi, & \Delta\eta, & \Delta\zeta \\ \delta\xi, & \delta\eta, & \delta\zeta \\ X, & Y, & Z \end{vmatrix}+\begin{vmatrix} a\Delta\xi+h\Delta\eta+g\Delta\zeta, & h\Delta\xi+b\Delta\eta+f\Delta\zeta, & g\Delta\xi+f\Delta\eta+c\Delta\zeta \\ X, & Y, & Z \\ \xi, & \eta, & \zeta \end{vmatrix},$$

which might be written

$$\begin{vmatrix} \Delta\xi, & \Delta\eta, & \Delta\zeta \\ \delta\xi, & \delta\eta, & \delta\zeta \\ X, & Y, & Z \end{vmatrix}-\begin{vmatrix} \delta\Delta\xi, & \delta\Delta\eta, & \delta\Delta\zeta \\ \xi, & \eta, & \zeta \\ X, & Y, & Z \end{vmatrix}$$

but it is perhaps more convenient to retain the second term in its original form.

29. As regards the first line, we have

$$\begin{aligned} A' &= 2h'Z'-2g'Y' \\ &= 2(h+\Delta h)(Z-V\partial_z\varrho)-2(g+\Delta g)(Y-V\partial_y\varrho) \\ &= A+2(Z\Delta h-Y\Delta g)-2V(h\partial_z\varrho-gd_y\varrho), \end{aligned}$$

with similar expressions for the other coefficients. Attending only to the terms of the first order, we thus obtain

$$\begin{aligned} A' &= A+2(Z\,\Delta h-Y\,\Delta g)-2V(hd_z-gd_y)\varrho, \\ B' &= B+2(X\Delta f-Z\,\Delta h)-2V(fd_x-hd_z)\varrho, \\ C' &= C+2(Y\Delta g-X\Delta f)-2V(gd_x-fd_x)\varrho, \\ F' &= F+Y\Delta h-Z\,\Delta g-X(\Delta b-\Delta c)-V(hd_y-gd_z-(b-c)d_x)\varrho. \\ G' &= G+Z\,\Delta f-X\Delta h-Y(\Delta c-\Delta a)-V(fd_z-hd_x-(c-a)d_y)\varrho, \\ H' &= H+X\Delta g-Y\Delta f-Z(\Delta a-\Delta b)-V(gd_x-fd_y-(a-b)d_z)\varrho. \end{aligned}$$

say these are $A'=A+\theta A$, &c., where θ is a functional symbol; we thus have $(A',\dots)(\xi',\eta',\zeta')^2=(A,\dots)(\xi,\eta,\zeta)^2+(\theta A,\dots)(\xi,\eta,\zeta)^2+2(A,\dots)(\xi,\eta,\zeta)(\Delta\xi,\Delta\eta,\Delta\zeta)$, which, for shortness, I represent by

$$=(A,\dots)(\xi,\eta,\zeta)^2+(A'',\dots)(\xi,\eta,\zeta)^2;$$

and I proceed to complete the calculation of the coefficients A″, B″, &c.

30. We have

$$A''=\theta A+\text{coeff. } \xi^2 \text{ in}$$

$$2[(A\xi+H\eta+G\zeta)\Delta\xi+(H\xi+B\eta+F\zeta)\Delta\eta+(G\xi+F\eta+C\zeta)\Delta\zeta]$$

$$=\theta A+2(Ad_x\varrho\alpha+Hd_x\varrho\beta+Gd_x\varrho\gamma),$$

that is

$$A''=\theta A+2\frac{1}{V}(AX+HY+GZ)d_x\varrho$$

$$+2\varrho(Ad_x\alpha+Hd_x\beta+Gd_x\gamma),$$

where coeff. 2ϱ is

$$=\frac{Aa+Hh+Gg}{V}-\frac{(AX+HY+GZ)\delta X}{V^3}$$

$$=\frac{1}{V}\left\{\omega(hZ-gY)+\bar{h}Z-\bar{g}Y\right\}-\frac{\delta X}{V^3}(Z\delta Y-Y\delta Z).$$

31. And similarly,

$$F''=\theta F+(H\alpha+B\beta+F\gamma)d_z\varrho+(G\alpha+F\beta+C\gamma)d_y\varrho$$

$$+\varrho\{(Hd_z\alpha+Bd_z\beta+Fd_z\gamma)+(Gd_y\alpha+Fd_y\beta+Cd_y\gamma)\}$$

$$=\theta F+\frac{1}{V}\{(HX+BY+FZ)d_z\varrho+(GX+FY+CZ)d_y\varrho\}$$

$$+\varrho\left\{\frac{Hg+Bf+Fc}{V}-\frac{(HX+BY+FZ)\delta Z}{V^3}\right.$$

$$\left.+\frac{Gh+Fb+Cf}{V}-\frac{(GX+FY+CZ)\delta Y}{V^3}\right\},$$

$$Gh+Fb+Cf=\quad\omega(hY-bX)+\bar{h}Y-\bar{b}X+\bar{\omega}X+\bar{a}X+\bar{h}Y+\bar{g}Z,$$

$$Hg+Bf+Fc=-\omega(gZ-cX)-\bar{g}Y+\bar{c}X-\bar{\omega}X-\bar{a}X-\bar{h}Y-\bar{g}Z.$$

Sum is $\omega\{hY-gZ-(b-c)X\}+\bar{h}Y-\bar{g}Z-(\bar{b}-\bar{c})X$, which is $=\omega F+\bar{h}Y-\bar{g}Z-(\bar{b}-\bar{c})X$: hence

$$F''=\theta F+(X\delta Z-Z\delta X)\left(\frac{1}{V}d_z\varrho-\frac{\varrho\delta Z}{V^3}\right)+(Y\delta X-X\delta Y)\left(\frac{1}{V}d_y\varrho-\frac{\varrho\delta Y}{V^3}\right)$$

$$+\frac{\varrho}{V}\{\omega F+\bar{h}Y-\bar{g}Z-(\bar{b}-\bar{c})X\}.$$

32. We may write

$$A''=\theta A+2\left(\frac{1}{V}d_x\varrho-\frac{\varrho\delta X}{V^3}\right)(Z\delta Y-Y\delta Z)+\frac{\varrho}{V}\{\omega A+\bar{A}\},$$

$$B''=\theta B+2\left(\frac{1}{V}d_y\varrho-\frac{\varrho\delta Y}{V^3}\right)(X\delta Z-Z\delta X)+\frac{\varrho}{V}\{\omega B+\bar{B}\},$$

$$C''=\theta C+2\left(\frac{1}{V}d_z\varrho-\frac{\varrho\delta Z}{V^3}\right)(Y\delta X-X\delta Y)+\frac{\varrho}{V}\{\omega C+\bar{C}\},$$

$$F''=\theta F+\left(\frac{1}{V}d_z\varrho-\frac{\varrho\delta Z}{V^3}\right)(X\delta Z-Z\delta X)+\left(\frac{1}{V}d_y\varrho-\frac{\varrho\delta Y}{V^3}\right)(Y\delta X-X\delta Y)+\frac{\varrho}{V}\{\omega F+\bar{F}\},$$

$$G''=\theta G+\left(\frac{1}{V}d_x\varrho-\frac{\varrho\delta X}{V^3}\right)(Y\delta X-X\delta Y)+\left(\frac{1}{V}d_z\varrho-\frac{\varrho\delta Z}{V^3}\right)(Z\delta Y-Y\delta Z)+\frac{\varrho}{V}\{\omega G+\bar{G}\},$$

$$H''=\theta H+\left(\frac{1}{V}d_y\varrho-\frac{\varrho\delta Y}{V^3}\right)(Z\delta Y-Y\delta Z)+\left(\frac{1}{V}d_x\varrho-\frac{\varrho\delta X}{V^3}\right)(X\delta Z-Z\delta X)+\frac{\varrho}{V}\{\omega H+\bar{H}\},$$

in which equations $\bar{A}$, $\bar{B}$, &c. are the like functions of $\bar{a}$, $\bar{b}$, &c. that A, B, &c. are of a, b, &c.; viz. $\bar{A}=2\bar{h}Z-2\bar{g}Y$, &c.

The value of θA is

$$\theta A=2Z\left(\left\{-\frac{\varrho}{V}(h\omega+\bar{h})+\frac{\varrho}{V^3}\delta X\delta Y\right\}-\frac{1}{V}(\delta Y d_x\varrho+\delta X d_y\varrho)-V d_x d_y\varrho\right)$$

$$-2Y\left(\left\{-\frac{\varrho}{V}(g\omega+\bar{g})+\frac{\varrho}{V^3}\delta Z\delta X\right\}-\frac{1}{V}(\delta Z\, d_x\varrho+\delta X d_z\varrho)-V d_x d_z\varrho\right)$$

$$-2V(hd_z-gd_y)\varrho,$$

which is

$$=-\frac{\varrho}{V}(\omega A+\bar{A}) \qquad +\frac{2\varrho}{V^3}\delta X(Z\delta Y-Y\delta Z)$$

$$-\frac{2\delta X}{V}(Zd_y-Yd_z)\varrho \quad -2V(hd_z-gd_y)\varrho$$

$$-\frac{2}{V}(Z\delta Y-Y\delta Z)d_x\varrho-2V(Zd_y-Yd_z)d_x\varrho.$$

Hence the value of A″ is equal to the last-mentioned expression, together with the following terms:—

$$+\frac{\varrho}{V}(\omega A+\bar{A})-\frac{2\varrho}{V^3}\delta X(Z\delta Y-Y\delta Z)+\frac{2}{V}(Z\delta Y-Y\delta Z)d_x\varrho,$$

which destroy certain of the foregoing ones; viz. we have

$$A''=\left(2Vg-\frac{2Z\delta X}{V}\right)d_y\varrho-2\left(Vh-\frac{2Y\delta X}{V}\right)d_z\varrho-2V(Zd_y-Yd_z)d_x\varrho.$$

33. Similarly, the value of θF is

$$\begin{aligned}\theta\mathrm{F}=\mathrm{Y}&\left(-\frac{\varrho}{\mathrm{V}}(h\omega+\bar{h})+\frac{\varrho}{\mathrm{V}^3}\delta\mathrm{X}\delta\mathrm{Y}-\frac{1}{\mathrm{V}}(\delta\mathrm{Y}d_x\varrho+\delta\mathrm{X}d_y\varrho)-\mathrm{V}d_xd_y\varrho\right)\\ -\mathrm{Z}&\left(-\frac{\varrho}{\mathrm{V}}(g\omega+\bar{g})+\frac{\varrho}{\mathrm{V}^3}\delta\mathrm{Z}\delta\mathrm{X}-\frac{1}{\mathrm{V}}(\delta\mathrm{Z}d_x\varrho+\delta\mathrm{X}d_z\varrho)-\mathrm{V}d_xd_z\varrho\right)\\ -\mathrm{X}&\left(-\frac{\varrho}{\mathrm{V}}\{(b-c)\omega+\bar{b}-\bar{c}\}+\frac{\varrho\delta\mathrm{Y}^2}{\mathrm{V}^3}-\frac{\varrho\delta\mathrm{Z}^2}{\mathrm{V}^3}\right.\\ &\qquad\qquad\left.-\frac{2}{\mathrm{V}}\delta\mathrm{Y}d_y\varrho+\frac{2}{\mathrm{V}}\delta\mathrm{Z}d_z\varrho-\mathrm{V}d_y^2\varrho+\mathrm{V}d_z^2\varrho\right)\\ -\mathrm{V}&(hd_y-gd_z-(b-c)d_x)\varrho,\end{aligned}$$

which is

$$\begin{aligned}&=\frac{\varrho}{\mathrm{V}}(-\mathrm{F}\omega-\bar{\mathrm{F}})+\frac{\varrho\delta\mathrm{Z}}{\mathrm{V}^3}(\mathrm{X}\delta\mathrm{Z}-\mathrm{Z}\delta\mathrm{X})+\frac{\varrho\delta\mathrm{Y}}{\mathrm{V}^3}(\mathrm{Y}\delta\mathrm{X}-\mathrm{X}\delta\mathrm{Y})\\ &\quad+\left\{-\frac{1}{\mathrm{V}}(\mathrm{Y}\delta\mathrm{Y}-\mathrm{Z}\delta\mathrm{Z})+\mathrm{V}(b-c)\right\}d_x\varrho\\ &\quad+\left\{-\frac{\mathrm{Y}}{\mathrm{V}}\delta\mathrm{X}+\frac{2\mathrm{X}}{\mathrm{V}}\delta\mathrm{Y}-\mathrm{V}h\right\}d_y\varrho\\ &\quad+\left\{\frac{\mathrm{Z}}{\mathrm{V}}\delta\mathrm{X}+\frac{2\mathrm{X}}{\mathrm{V}}\delta\mathrm{Y}+\mathrm{V}g\right\}d_z\varrho\\ &\quad+(-\mathrm{VY}d_xd_y+\mathrm{VZ}d_xd_z+\mathrm{VX}d_y^2-\mathrm{VX}d_z^2)\varrho.\end{aligned}$$

Hence F$''$ is equal to the foregoing expression, together with the following terms:—

$$\begin{aligned}&+\frac{\varrho}{\mathrm{V}}(\mathrm{F}\omega+\bar{\mathrm{F}})-\frac{\varrho\delta\mathrm{Z}}{\mathrm{V}^3}(\mathrm{X}\delta\mathrm{Z}-\mathrm{Z}\delta\mathrm{X})-\frac{\varrho\delta\mathrm{Y}}{\mathrm{V}^3}(\mathrm{Y}\delta\mathrm{X}-\mathrm{X}\delta\mathrm{Y})\\ &\quad+\frac{1}{\mathrm{V}}(\mathrm{Y}\delta\mathrm{X}-\mathrm{X}\delta\mathrm{Y})d_y\varrho+\frac{1}{\mathrm{V}}(\mathrm{X}\delta\mathrm{Z}-\mathrm{Z}\delta\mathrm{X})d_z\varrho,\end{aligned}$$

which destroy certain of the foregoing terms; viz. we thus have

$$\begin{aligned}\mathrm{F}''=&\left\{-\frac{1}{\mathrm{V}}(\mathrm{Y}\delta\mathrm{Y}-\mathrm{Z}\delta\mathrm{Z})+\mathrm{V}(b-c)\right\}d_x\varrho+\left\{\frac{\mathrm{X}}{\mathrm{V}}\delta\mathrm{Y}-\mathrm{V}h\right\}d_y\varrho+\left\{-\frac{\mathrm{X}}{\mathrm{V}}\delta\mathrm{Z}-\mathrm{V}g\right\}d_z\varrho\\ &+\mathrm{V}(-\mathrm{Y}d_xd_y+\mathrm{Z}d_zd_x+\mathrm{X}d_y^2-\mathrm{X}d_z^2)\varrho.\end{aligned}$$

34. We thus have

$$\begin{aligned}\mathrm{A}''&=\qquad\cdot\qquad 2\left(\mathrm{V}g-\frac{\mathrm{Z}\delta\mathrm{X}}{\mathrm{V}}\right)d_y\varrho-2\left(\mathrm{V}h-\frac{\mathrm{Y}\delta\mathrm{X}}{\mathrm{V}}\right)d_z\varrho+2\mathrm{V}(-\mathrm{Z}d_yd_x+\mathrm{Y}d_zd_x)\varrho,\\ \mathrm{B}''&=-2\left(\mathrm{V}f-\frac{\mathrm{Z}\delta\mathrm{Y}}{\mathrm{V}}\right)d_x\varrho\qquad\cdot\qquad+2\left(\mathrm{V}h-\frac{\mathrm{X}\delta\mathrm{Y}}{\mathrm{V}}\right)d_z\varrho+2\mathrm{V}(-\mathrm{X}d_zd_y+\mathrm{Z}d_xd_y)\varrho,\\ \mathrm{C}''&=+2\left(\mathrm{V}f-\frac{\mathrm{Y}\delta\mathrm{Z}}{\mathrm{V}}\right)d_x\varrho-2\left(\mathrm{V}g-\frac{\mathrm{X}\delta\mathrm{Z}}{\mathrm{V}}\right)d_y\varrho\qquad\cdot\qquad+2\mathrm{V}(-\mathrm{Y}d_xd_z+\mathrm{X}d_yd_z)\varrho,\end{aligned}$$

$$\begin{aligned}\mathrm{F}'' &= \left\{\mathrm{V}(b-c)-\frac{1}{\mathrm{V}}(\mathrm{Y}\delta\mathrm{Y}-\mathrm{Z}\delta\mathrm{Z})\right\}d_x\varrho-\left(\mathrm{V}h-\frac{\mathrm{X}\delta\mathrm{Y}}{\mathrm{V}}\right)d_y\varrho+\left(\mathrm{V}g-\frac{\mathrm{X}\delta\mathrm{Z}}{\mathrm{V}}\right)d_z\varrho\\ &\qquad +\mathrm{V}(-\mathrm{Y}d_xd_y+\mathrm{Z}d_xd_z+\mathrm{X}d_y^2-\mathrm{X}d_z^2)\varrho,\\ \mathrm{G}'' &= \left(\mathrm{V}h-\frac{\mathrm{Y}\delta\mathrm{X}}{\mathrm{V}}\right)d_x\varrho+\mathrm{V}\left\{(c-a)-\frac{1}{\mathrm{V}}(\mathrm{Z}\delta\mathrm{Z}-\mathrm{X}\delta\mathrm{X})\right\}d_y\varrho-\left(\mathrm{V}f-\frac{\mathrm{Y}\delta\mathrm{Z}}{\mathrm{V}}\right)d_z\varrho\\ &\qquad +\mathrm{V}(-\mathrm{Z}d_yd_z+\mathrm{X}d_yd_x+\mathrm{Y}d_z^2-\mathrm{Y}d_x^2)\varrho,\\ \mathrm{H}'' &= -\left(\mathrm{V}g-\frac{\mathrm{Z}\delta\mathrm{X}}{\mathrm{V}}\right)d_x\varrho-\left(\mathrm{V}f-\frac{\mathrm{Z}\delta\mathrm{Y}}{\mathrm{V}}\right)d_y\varrho+\left\{\mathrm{V}(a-b)-\frac{1}{\mathrm{V}}(\mathrm{X}\delta\mathrm{X}-\mathrm{Y}\delta\mathrm{Y})\right\}d_z\varrho\\ &\qquad +\mathrm{V}(-\mathrm{X}d_zd_x+\mathrm{Y}d_zd_y+\mathrm{Z}d_x^2-\mathrm{Z}d_y^2)\varrho.\end{aligned}$$

35. It will be recollected that we have $\mathrm{X}'\xi'+\mathrm{Y}'\eta'+\mathrm{Z}'\zeta'=\mathrm{X}\xi+\mathrm{Y}\eta+\mathrm{Z}\zeta$; by what precedes it appears that for the given surface the principal tangents are determined by the equations

$$(\mathrm{A},\ldots\between\xi,\eta,\zeta)^2=0,$$
$$\mathrm{X}\xi+\mathrm{Y}\eta+\mathrm{Z}\zeta=0,$$

and that the lines which (in the tangent plane of the given surface) correspond to the principal tangents of the corresponding point of the vicinal surface are determined by the equations

$$(\mathrm{A},\ldots\between\xi,\eta,\zeta)^2+(\mathrm{A}'',\ldots\between\xi,\eta,\zeta)^2=0,$$
$$\mathrm{X}\xi+\mathrm{Y}\eta+\mathrm{Z}\zeta=0.$$

Condition that the two surfaces may belong to an Orthogonal System.
Article Nos. 36 to 41.

36. The condition in order that the two surfaces may belong to an orthogonal system is that the principal tangents shall correspond, or, what is the same thing, the lines which (in the tangent plane of the given surface) correspond to the principal tangents of the vicinal surface must be the principal tangents of the given surface. When this is the case the plane and cone $\mathrm{X}\xi+\mathrm{Y}\eta+\mathrm{Z}\zeta=0$, $(\mathrm{A}'',\ldots\between\xi,\eta,\zeta)^2=0$ intersect in the principal tangents, and this is therefore the required condition.

The plane $\mathrm{X}\xi+\mathrm{Y}\eta+\mathrm{Z}\zeta=0$ meets the cone $(\mathrm{A}'',\ldots\between\xi,\eta,\zeta)^2=0$ in the principal tangents, that is in a pair of lines harmonically related to the circular lines and also to the chief tangents. Forming then the coefficients (A''), (B''), (C''), (F''), (G''), (H'') from A'', &c. in the same way as (A) &c. are formed from A, &c., that is, writing $(\mathrm{A}'')=\mathrm{B}''\mathrm{Z}^2+\mathrm{C}''\mathrm{Y}^2-2\mathrm{F}''\mathrm{YZ}$, &c., the conditions are

$$(\mathrm{A}'')+(\mathrm{B}'')+(\mathrm{C}'')=0,$$
$$((\mathrm{A}''),\ldots\between a,\ldots)=0, \text{ or, what is the same thing,}$$
$$(\mathrm{A}'',\ldots\between(a),\ldots)=0.$$

The former of these, as about to be shown, is satisfied identically; we have therefore the second of them, say $(\mathrm{A}'',\ldots\between(a),\ldots)=0$ as the required condition.

37. We have

$$(\mathrm{A}'')+(\mathrm{B}'')+(\mathrm{C}'')=(\mathrm{A}''+\mathrm{B}'+\mathrm{C}'')\mathrm{V}^2-(\mathrm{A}'',\,..\between \mathrm{X},\mathrm{Y},\mathrm{Z})^2,$$

$$\mathrm{A}''+\mathrm{B}''+\mathrm{C}''=\frac{2}{\mathrm{V}}\{(\mathrm{Z}\delta\mathrm{Y}-\mathrm{Y}\delta\mathrm{Z})d_x\varrho+(\mathrm{X}\delta\mathrm{Z}-\mathrm{Z}\delta\mathrm{X})d_y\varrho+(\mathrm{Y}\delta\mathrm{X}-\mathrm{X}\delta\mathrm{Y})d_z\varrho\}.$$

Forming next the expressions of $\mathrm{A}''\mathrm{X}+\mathrm{H}''\mathrm{Y}+\mathrm{G}''\mathrm{Z}$ &c., and, for convenience, writing down separately the terms which involve the second differential coefficients of ϱ, we have

$$\mathrm{A}''\mathrm{X}+\mathrm{H}''\mathrm{Y}+\mathrm{G}''\mathrm{Z}=$$
$$d_x\varrho\,.\,\mathrm{V}(h\mathrm{Z}-g\mathrm{Y})+d_y\varrho[\mathrm{V}\delta\mathrm{Z}-\mathrm{Z}\delta\mathrm{V}+\mathrm{V}(g\mathrm{X}-a\mathrm{Z})]+d_z\varrho[-(\mathrm{V}\delta\mathrm{Y}-\mathrm{Y}\delta\mathrm{V})-\mathrm{V}(h\mathrm{X}-a\mathrm{Y})],$$
$$\mathrm{H}''\mathrm{X}+\mathrm{B}''\mathrm{Y}+\mathrm{F}''\mathrm{Z}=$$
$$d_x\varrho[-(\mathrm{V}\delta\mathrm{Z}-\mathrm{Z}\delta\mathrm{V})-\mathrm{V}(f\mathrm{Y}-b\mathrm{Z})]+d_y\varrho\,.\,\mathrm{V}(f\mathrm{X}-h\mathrm{Z})+d_z\varrho[(\mathrm{V}\delta\mathrm{X}-\mathrm{X}\delta\mathrm{V})+\mathrm{V}(h\mathrm{Y}-b\mathrm{X})],$$
$$\mathrm{G}''\mathrm{X}+\mathrm{F}''\mathrm{Y}+\mathrm{C}''\mathrm{Z}=$$
$$d_x\varrho[\mathrm{V}\delta\mathrm{Y}-\mathrm{Y}\delta\mathrm{V}+\mathrm{V}(f\mathrm{Z}-c\mathrm{Y})]+d_y\varrho[-(\mathrm{V}\delta\mathrm{X}-\mathrm{X}\delta\mathrm{V})-\mathrm{V}(g\mathrm{Z}-c\mathrm{X})]+d_z\varrho\,.\,\mathrm{V}(g\mathrm{Y}-f\mathrm{X}),$$

where $\delta\mathrm{V}$ stands for $\frac{1}{\mathrm{V}}(\mathrm{X}\delta\mathrm{X}+\mathrm{Y}\delta\mathrm{Y}+\mathrm{Z}\delta\mathrm{Z})$, and where the three expressions contain also the following terms respectively:—

$$\begin{array}{lllllll}
\{ & . & -\mathrm{YZ}d_y^2 & +\mathrm{YZ}d_z^2+ & (\mathrm{Y}^2-\mathrm{Z}^2)d_yd_z+ & \mathrm{XY}d_zd_x- & \mathrm{XZ}d_xd_y\}\varrho,\\
\{ & \mathrm{ZX}d_x^2 & . & -\mathrm{ZX}d_z^2- & \mathrm{XY}d_yd_z+ & (\mathrm{Z}^2-\mathrm{X}^2)d_zd_x+ & \mathrm{YZ}d_xd_y\}\varrho,\\
\{ & -\mathrm{XY}d_x^2 & +\mathrm{XY}d_y^2 & .\quad + & \mathrm{XZ}d_yd_z- & \mathrm{YZ}d_zd_x+ & (\mathrm{X}^2-\mathrm{Y}^2)d_xd_y\}\varrho.
\end{array}$$

Multiplying by X, Y, Z, and adding, the terms which contain the second differential coefficients disappear, and we obtain

$$(\mathrm{A}'',\,..\between \mathrm{X},\mathrm{Y},\mathrm{Z})^2=2\mathrm{V}[(\mathrm{Z}\delta\mathrm{Y}-\mathrm{Y}\delta\mathrm{Z})d_x\varrho+(\mathrm{X}\delta\mathrm{Z}-\mathrm{Z}\delta\mathrm{X})d_y\varrho+(\mathrm{Y}\delta\mathrm{X}-\mathrm{X}\delta\mathrm{Y})d_z\varrho];$$

so that, attending to the above value of $\mathrm{A}''+\mathrm{B}''+\mathrm{C}''$, we have the required equation

$$(\mathrm{A}'')+(\mathrm{B}'')+(\mathrm{C}'')=0.$$

38. Proceeding now to form the value of $(\mathrm{A}'',\,...\between(a),\,...)$, that is

$$\mathrm{A}''(a)+\mathrm{B}''(b)+\mathrm{C}''(c)+2\mathrm{F}''(f)+2\mathrm{G}''(g)+2\mathrm{H}''(h),$$

it will be shown that the terms involving the first differential coefficients of ϱ vanish of themselves; as regards those containing the second differential coefficients, forming the auxiliary equations

$$(\mathrm{A})=2(h)\mathrm{Z}\;-2(g)\mathrm{Y},$$
$$(\mathrm{B})=2(f)\mathrm{X}-2(h)\mathrm{Z},$$
$$(\mathrm{C})=2(g)\mathrm{Y}\;-2(f)\mathrm{X},$$
$$(\mathrm{F})=(h)\mathrm{Y}-(g)\mathrm{Z}\;-((b)-(c))\mathrm{X},$$
$$(\mathrm{G})=(f)\mathrm{Z}-(h)\mathrm{X}\;-((c)-(a))\mathrm{Y},$$
$$(\mathrm{H})=(g)\mathrm{X}-(f)\mathrm{Y}-((a)-(b))\mathrm{Z},$$

we find without difficulty that the terms in question (being, in fact, the complete value of the expression) are

$$=\mathrm{V}((\mathrm{A}),\ldots\between d_x, d_y, d_z)^2\varrho.$$

39. As regards the terms involving the first differential coefficients, observe that the whole coefficient of $\delta_x\varrho$ is

$$\begin{aligned}&-2(b)\left(\mathrm{V}f-\frac{\mathrm{Z}\delta\mathrm{Y}}{\mathrm{V}}\right)\\ &+2(c)\left(\mathrm{V}g-\frac{\mathrm{Y}\delta\mathrm{Z}}{\mathrm{V}}\right)\\ &+2(f)\left(\mathrm{V}(b-c)-\frac{1}{\mathrm{V}}(\mathrm{Y}\delta\mathrm{Y}-\mathrm{Z}\delta\mathrm{Z})\right)\\ &+2(g)\left(\mathrm{V}h-\frac{\mathrm{Y}\delta\mathrm{X}}{\mathrm{V}}\right)\\ &-2(h)\left(\mathrm{V}g-\frac{\mathrm{Z}\delta\mathrm{X}}{\mathrm{V}}\right),\end{aligned}$$

which is

$$\begin{aligned}&=2\mathrm{V}\{(g)h+(f)b+(c)g-((h)g+(h)f+(f)c)\}\\ &+\frac{2}{\mathrm{V}}\{\mathrm{Z}((h)\delta\mathrm{X}+(b)\delta\mathrm{Y}+(f)\delta\mathrm{Z})-\mathrm{Y}((g)\delta\mathrm{X}+(f)\delta\mathrm{Y}+(c)\delta\mathrm{Z})\}.\end{aligned}$$

40. The reduction depends on the following auxiliary formulæ:—

$$\begin{array}{l||l||l} a(a)+h(h)+g(g)=\mathrm{V}\bar\delta\mathrm{V}-\mathrm{X}\bar\delta\mathrm{X}, & a(h)+h(h)+g(f)=\quad-\mathrm{X}\bar\delta\mathrm{Y}, & a(g)+h(f)+g(c)=\quad-\mathrm{X}\bar\delta\mathrm{Z},\\ h\ ,,\ +h\ ,,\ +f\ ,,\ =\quad-\mathrm{Y}\bar\delta\mathrm{X}, & h\ ,,\ +b\ ,,\ +f\ ,,\ =\mathrm{V}\bar\delta\mathrm{V}-\mathrm{Y}\bar\delta\mathrm{Y}, & h\ ,,\ +b\ ,,\ +f\ ,,=\quad-\mathrm{Y}\bar\delta\mathrm{Z},\\ g\ ,,\ +f\ ,,\ +c\ ,,\ =\quad-\mathrm{Z}\bar\delta\mathrm{X}, & g\ ,,\ +f\ ,,\ +c\ ,,\ =\quad-\mathrm{Z}\bar\delta\mathrm{Y}, & g\ ,,\ +f\ ,,\ +c\ ,,=\mathrm{V}\bar\delta\mathrm{V}-\mathrm{Z}\bar\delta\mathrm{Z},\end{array}$$

where, for shortness, I have written $\bar\delta\mathrm{X}$, $\bar\delta\mathrm{Y}$, $\bar\delta\mathrm{Z}$ to stand for $\bar{a}\mathrm{X}+\bar{h}\mathrm{Y}+\bar{g}\mathrm{Z}$, $\bar{h}\mathrm{X}+\bar{h}\mathrm{Y}+\bar{f}\mathrm{Z}$, $\bar{g}\mathrm{X}+\bar{f}\mathrm{Y}+\bar{c}\mathrm{Z}$ respectively, and $\mathrm{V}\bar\delta\mathrm{V}$ for $\mathrm{X}\bar\delta\mathrm{X}+\mathrm{Y}\bar\delta\mathrm{Y}+\mathrm{Z}\bar\delta\mathrm{Z}$, $(=\bar{a},\,..\between\mathrm{X},\mathrm{Y},\mathrm{Z})^2$.

From these we immediately have

$$\begin{aligned}(a)\delta\mathrm{X}+(h)\delta\mathrm{Y}+(g)\delta\mathrm{Z}&=\mathrm{V}(\mathrm{X}\bar\delta\mathrm{V}-\mathrm{V}\bar\delta\mathrm{X}),\\ (h)\delta\mathrm{X}+(b)\delta\mathrm{Y}+(f)\delta\mathrm{Z}&=\mathrm{V}(\mathrm{Y}\bar\delta\mathrm{V}-\mathrm{V}\bar\delta\mathrm{Y}),\\ (a)\delta\mathrm{X}+(f)\delta\mathrm{Y}+(c)\,\delta\mathrm{Z}&=\mathrm{V}(\mathrm{Z}\bar\delta\mathrm{V}-\mathrm{V}\bar\delta\mathrm{Z}).\end{aligned}$$

Hence, in the coefficient of $d_x\varrho$, the first line is

$$=2\mathrm{V}(-\mathrm{Y}\bar\delta\mathrm{Z}+\mathrm{Z}\bar\delta\mathrm{Y}),$$

and the second line is

$$=\frac{2}{\mathrm{V}}\{\mathrm{VZ}(\mathrm{Y}\bar\delta\mathrm{V}-\mathrm{V}\bar\delta\mathrm{Y})-\mathrm{VY}(\mathrm{Z}\bar\delta\mathrm{V}-\mathrm{V}\bar\delta\mathrm{Z})\},\ =2\mathrm{V}(\mathrm{Y}\bar\delta\mathrm{Z}-\mathrm{Z}\bar\delta\mathrm{Y});$$

so that the sum, or whole coefficient of $d_x\varrho$, is $=0$. Similarly, the coefficients of $d_y\varrho$ and $d_z\varrho$ are each $=0$.

41. We have thus arrived at the equation

$$((\mathrm{A}), \ldots \big)\!\big(d_x,\ d_y,\ d_z)^2 \varrho = 0$$

as the condition to be satisfied by the normal distance ϱ in order that the given surface and the vicinal surface may belong to an orthogonal system, viz. this is a partial differential equation of the second order, its coefficients being given functions of X, Y, Z, a, b, c, f, g, h, the first and second differential coefficients of r (where $r=r(x, y, z)$ is the equation of the given surface).

The equation, it is clear, may also be written in the two forms

$$(\mathrm{A}, \ldots \big)\!\big(\mathrm{Z}d_y-\mathrm{Y}d_z,\ \mathrm{X}d_z-\mathrm{Z}d_x,\ \mathrm{Y}d_x-\mathrm{X}d_y)^2\varrho=0,$$

and

$$\left|\begin{matrix} \mathrm{P} & , & \mathrm{Q} & , & \mathrm{R} \\ a\mathrm{P}+h\mathrm{Q}+g\mathrm{R}, & & h\mathrm{P}+b\mathrm{Q}+f\mathrm{R}, & & g\mathrm{P}+f\mathrm{Q}+c\mathrm{R} \\ \mathrm{X} & , & \mathrm{Y} & , & \mathrm{Z} \end{matrix}\right| \varrho=0,$$

if, for shortness, P, Q, R are written to denote $\mathrm{Z}d_y-\mathrm{Y}d_z$, $\mathrm{X}d_z-\mathrm{Z}d_x$, $\mathrm{Y}d_x-\mathrm{X}d_y$ respectively, it being understood that in each of these forms the d_x, d_y, d_z operate on the ϱ only.

Condition that a family of surfaces may belong to an Orthogonal System.
Article Nos. 42 to 49.

42. We pass at once to the condition in order that the family of surfaces

$$r-r(x, y, z)=0$$

may belong to an orthogonal system, viz., when the vicinal surface belongs to the family, we have ϱ proportional to $\frac{1}{\mathrm{V}}\left(=\frac{1}{\sqrt{\mathrm{X}^2+\mathrm{Y}^2+\mathrm{Z}^2}}\right)$, and the condition is

$$((\mathrm{A}), \ldots \big)\!\big(d_x,\ d_y,\ d_z)^2\frac{1}{\mathrm{V}}=0,$$

where r is a function of (x, y, z), the first and second differential coefficients of which are X, Y, Z, a, b, c, f, g, h; and the equation is thus a partial differential equation of the third order satisfied by r. The form is by no means an inconvenient one, but it admits of further reduction.

43. We have $d_x\frac{1}{\mathrm{V}}$, $d_y\frac{1}{\mathrm{V}}$, $d_z\frac{1}{\mathrm{V}}$ equal to $-\frac{1}{\mathrm{V}^3}\,\delta\mathrm{X}$, $-\frac{1}{\mathrm{V}^3}\,\delta\mathrm{Y}$, $-\frac{1}{\mathrm{V}^3}\,\delta\mathrm{Z}$ respectively, and thence

$$d_x^2\frac{1}{\mathrm{V}}=-\frac{1}{\mathrm{V}^3}(a^2+h^2+g^2+\delta a) \quad +\frac{3}{\mathrm{V}^5}(\delta\mathrm{X})^2,$$

$$d_yd_z\frac{1}{\mathrm{V}}=-\frac{1}{\mathrm{V}^3}(gh+bf+cf+\delta f)+\frac{3}{\mathrm{V}^5}\,\delta\mathrm{Y}\delta\mathrm{Z},$$

or, as these may be written,

$$d_x^2\frac{1}{\mathrm{V}}=-\frac{1}{\mathrm{V}^3}(a\omega-\bar{\omega}+\bar{a}+\delta a)+\frac{3}{\mathrm{V}^5}(\delta\mathrm{X})^2,$$

$$d_yd_z\frac{1}{\mathrm{V}}=-\frac{1}{\mathrm{V}^3}(f\omega \quad +\bar{f}+\delta f)+\frac{3}{\mathrm{V}^5}\delta\mathrm{Y}\delta\mathrm{Z},$$

with the like values for $d_y^2\frac{1}{V}$, &c. Substituting, the equation contains a term multiplied by ω, viz. this is

$$-\frac{1}{V^3}\omega((A),\,..\between a,\,..),$$

which vanishes; and a term multiplied by $\bar{\omega}$, viz. this is

$$\frac{1}{V^3}\bar{\omega}((A)+(B)+(C)),$$

which also vanishes. Writing down the remaining terms, and multiplying the whole by $-V^3$, the equation becomes

$$((A),\,..\between\bar{a},\,..)+((A),\,..\between\delta a,\,..)-\frac{3}{V^2}((A),\,...\between\delta X,\,\delta Y,\,\delta Z)^2=0.$$

44. The last term admits of reduction; from the equations

$$(A)=-AV^2+2XZ\delta Y-2XY\delta Z,\ \text{\&c., we find}$$

$$(A)\delta X+(H)\delta Y+(G)\delta Z=-V^2(A\delta X+H\delta Y+G\delta Z)+V\delta V(Z\delta Y-Y\delta Z),$$

$$(H)\delta X+(B)\delta Y+(F)\delta Z=-V^2(H\delta X+B\delta Y+F\delta Z)+V\delta V(X\delta Z-Z\delta X),$$

$$(G)\delta X+(F)\delta Y+(C)\delta Z=-V^2(G\delta X+F\delta Y+C\delta Z)+V\delta V(Y\delta X-X\delta Y),$$

and hence

$$((A),\,..\between\delta X,\,\delta Y,\,\delta Z)^2=-V^2(A,\,...\between\delta X,\,\delta Y,\,\delta Z)^2\,;$$

wherefore the equation becomes

$$((A),\,..\between\bar{a},\,..)+((A),\,..\between\delta a\,..)+3(A,\,..\between\delta X,\,\delta Y,\,\delta Z)^2=0.$$

45. It will be shown that we have identically

$$((A),\,...\between\bar{a},\,...)=-(A,\,..\between\delta X,\,\delta Y,\,\delta Z)^2=2\begin{vmatrix}\delta X, & \delta Y, & \delta Z\\ X, & Y, & Z\\ \bar{\delta}X, & \bar{\delta}Y, & \bar{\delta}Z\end{vmatrix}.$$

The partial differential equation thus assumes the form

$$((A),\,..\between\delta a,\,...)+\Omega=0,$$

where Ω may be expressed indifferently in the three forms,

$$\begin{aligned}&=+2(A,\,..\between\bar{a},\,..),\\ &=+2(A,\,..\between\delta X,\,\delta Y,\,\delta Z)^2,\\ &=-4\begin{vmatrix}\delta X, & \delta Y, & \delta Z\\ X, & Y, & Z\\ \bar{\delta}X, & \bar{\delta}Y, & \bar{\delta}Z\end{vmatrix}.\end{aligned}$$

46. Taking the first of these, the partial differential equation is

$$((A),\,...\between\delta a,\,..)-2((A),\,..\between\bar{a},\,...)=0\,;$$

or, written at full length, it is

$$\begin{aligned}&(\mathrm{A})\delta a+(\mathrm{B})\delta b+(\mathrm{C})\delta c+2(\mathrm{F})\delta f+2(\mathrm{G})\delta g+2(\mathrm{H})\delta h\\ -2\{&(\mathrm{A})\bar{a}+(\mathrm{B})\bar{b}+(\mathrm{C})\bar{c}+2(\mathrm{F})\bar{f}+2(\mathrm{G})\bar{g}+2(\mathrm{H})\bar{h}\}=0,\end{aligned}$$

where the coefficients are given functions of X, Y, Z, a, b, c, f, g, h, the first and second differential coefficients of r; and δ is written to denote $\mathrm{X}d_x+\mathrm{Y}d_y+\mathrm{Z}d_z$.

47. It remains to prove the above-mentioned identities.

To reduce the term $(\mathrm{A},\ldots\between\delta\mathrm{X},\delta\mathrm{Y},\delta\mathrm{Z})^2$, we have

$$\begin{aligned}&\mathrm{A}\delta\mathrm{X}+\mathrm{H}\delta\mathrm{Y}+\mathrm{G}\delta\mathrm{Z}\\ &\quad=\mathrm{A}(a\mathrm{X}+h\mathrm{Y}+g\mathrm{Z})+\mathrm{H}(h\mathrm{X}+b\mathrm{Y}+f\mathrm{Z})+\mathrm{G}(g\mathrm{X}+f\mathrm{Y}+c\mathrm{Z})\\ &\quad=\mathrm{X}\{\ \omega(h\mathrm{Z}-g\mathrm{Y})+\bar{h}\mathrm{Z}-\bar{g}\mathrm{Y}\}\\ &\qquad+\mathrm{Y}\{-\omega(f\mathrm{Y}-b\mathrm{Z})-(\bar{f}\mathrm{Y}-\bar{b}\mathrm{Z})-\bar{\omega}\mathrm{Z}-\bar{\delta}\mathrm{Z}\}\\ &\qquad+\mathrm{Z}\{\ \omega(f\mathrm{Z}-c\mathrm{Y})+\bar{f}\mathrm{Z}-\bar{c}\mathrm{Y}+\bar{\omega}\mathrm{Y}+\bar{\delta}\mathrm{Z}\}\\ &\quad=\omega(\mathrm{Z}\delta\mathrm{Y}-\mathrm{Y}\delta\mathrm{Z})+(\mathrm{Z}\bar{\delta}\mathrm{Y}-\mathrm{Y}\bar{\delta}\mathrm{Z})+(\mathrm{Z}\bar{\delta}\mathrm{Y}-\mathrm{Y}\bar{\delta}\mathrm{Z}),\end{aligned}$$

that is

$$\begin{aligned}\mathrm{A}\delta\mathrm{X}+\mathrm{H}\delta\mathrm{Y}+\mathrm{G}\delta\mathrm{Z}&=\omega(\mathrm{Z}\delta\mathrm{Y}-\mathrm{Y}\delta\mathrm{Z})+2(\mathrm{Z}\bar{\delta}\mathrm{Y}-\mathrm{Y}\bar{\delta}\mathrm{Z}),\text{ and similarly}\\ \mathrm{H}\delta\mathrm{X}+\mathrm{B}\delta\mathrm{Y}+\mathrm{F}\delta\mathrm{Z}&=\omega(\mathrm{X}\delta\mathrm{Z}-\mathrm{Z}\delta\mathrm{X})+2(\mathrm{X}\bar{\delta}\mathrm{Z}-\mathrm{Z}\bar{\delta}\mathrm{X}),\\ \mathrm{G}\delta\mathrm{X}+\mathrm{F}\delta\mathrm{Y}+\mathrm{C}\delta\mathrm{Z}&=\omega(\mathrm{Y}\delta\mathrm{X}-\mathrm{X}\delta\mathrm{Y})+2(\mathrm{Y}\bar{\delta}\mathrm{X}-\mathrm{X}\bar{\delta}\mathrm{Y}),\end{aligned}$$

whence

$$(\mathrm{A},\ldots\between\delta\mathrm{X},\delta\mathrm{Y},\delta\mathrm{Z})^2=-2\begin{vmatrix}\delta\mathrm{X}, & \delta\mathrm{Y}, & \delta\mathrm{Z}\\ \mathrm{X}, & \mathrm{Y}, & \mathrm{Z}\\ \bar{\delta}\mathrm{X}, & \bar{\delta}\mathrm{Y}, & \bar{\delta}\mathrm{Z}\end{vmatrix}.$$

48. Now, from the equations $\mathrm{AX}+\mathrm{HY}+\mathrm{GZ}=\mathrm{Z}\delta\mathrm{Y}-\mathrm{Y}\delta\mathrm{Z}$, &c., we have for the value of twice the foregoing determinant

$$\begin{aligned}2\text{ det.}=2\{&(\bar{a}\mathrm{X}+\bar{h}\mathrm{Y}+\bar{g}\mathrm{Z})(\mathrm{AX}+\mathrm{HY}+\mathrm{GZ})\\ +&(\bar{h}\mathrm{X}+\bar{b}\mathrm{Y}+\bar{f}\mathrm{Z})(\mathrm{HX}+\mathrm{BY}+\mathrm{FZ})\\ +&(\bar{g}\mathrm{X}+\bar{f}\mathrm{Y}+\bar{c}\mathrm{Z})(\mathrm{GX}+\mathrm{FY}+\mathrm{CZ})\};\end{aligned}$$

and subtracting herefrom the function $((\mathrm{A}),\ldots\between\bar{a},\ldots)$, which is

$$\begin{aligned}=\quad&(\mathrm{BZ}^2+\mathrm{CY}^2-2\mathrm{FYZ})\bar{a}\\ +&(\mathrm{CX}^2+\mathrm{AZ}^2-2\mathrm{GZX})\bar{b}\\ +&(\mathrm{AY}^2+\mathrm{BX}^2-2\mathrm{FYZ})\bar{c}\\ +2&(-\mathrm{AYZ}-\mathrm{FX}^2+\mathrm{GXY}+\mathrm{HXZ})\bar{f}\\ +2&(-\mathrm{BZX}+\mathrm{FXY}-\mathrm{GY}^2+\mathrm{HYZ})\bar{g}\\ +2&(-\mathrm{CXY}+\mathrm{FXZ}+\mathrm{GYZ}-\mathrm{HZ}^2)\bar{h},\end{aligned}$$

the difference is found to be

$$\begin{aligned} = \;& \bar{a}\{(A, \,..\between X,\, Y,\, Z)^2+AV^2\} \\ &+\bar{b}\{(A, \,..\between X,\, Y,\, Z)^2+BV^2\} \\ &+\bar{c}\{(A, \,..\between X,\, Y,\, Z)^2+CV^2\} \\ &+2\bar{f}\{(A+B+C)YZ+FV^2\} \\ &+2\bar{g}\{(A+B+C)ZX+GV^2\} \\ &+2\bar{h}\{(A+B+C)XY+HV^2\}, \end{aligned}$$

which, on account of $(A, \,..\between X,\, Y,\, Z)^2=0$, and $A+B+C=0$, reduces itself to

$$(A, \,..\between \bar{a}, \,\ldots).\,V^2.$$

49. We have

$$\begin{aligned} A\bar{a}+H\bar{h}+G\bar{g}= \;& a(2hZ-2gY) \\ &+\bar{h}(\;gX-\;fY-(a-b)Z) \\ &+\bar{g}(\;fZ-\;hX-(c-a)Y) \\ = \;& X(\bar{h}g-h\bar{g}) \\ &+Y(a\bar{g}-g\bar{a}-(g\bar{a}+f\bar{h}+c\bar{g})) \\ &+Z(h\bar{a}-a\bar{h}+(h\bar{a}+b\bar{h}+f\bar{g})); \end{aligned}$$

or observing that in the coefficients of Y and Z the second terms each vanish, this is

$$\begin{aligned} &A\bar{a}+H\bar{h}+G\bar{g}=X(\bar{h}g-\bar{g}h)+Y(\bar{g}a-\bar{a}g)+Z(a\bar{h}-\bar{h}a), \text{ and similarly} \\ &H\bar{h}+B\,\bar{b}+F\bar{f}=X(\bar{b}f-\bar{f}b)+Y(\bar{f}h-\bar{h}f)+Y(\bar{h}b-\bar{b}h), \\ &G\bar{g}+H\bar{h}+F\bar{c}=X(\bar{f}c-\bar{c}f)+Y(\bar{c}g-\bar{g}c)+Z(\bar{g}f-\bar{f}g). \end{aligned}$$

Adding these equations, the coefficient of X is the difference of two expressions each of which vanishes; and the like as regards the coefficients of Y and Z; that is, we have

$$(A, \,..\between \bar{a}, \,..)=0;$$

and consequently

$$2\begin{vmatrix} \delta X, & \delta Y, & \delta Z \\ X, & Y, & Z \\ \bar{\delta}X, & \bar{\delta}Y, & \bar{\delta}Z \end{vmatrix} =((A), \,..\between \bar{a}, \,\ldots)=-(A, \,\ldots\between \delta X,\, \delta Y,\, \delta Z)^2,$$

the required relation.

V. *Researches in Spectrum-Analysis in connexion with the Spectrum of the Sun.*

By J. Norman Lockyer, *F.R.S.*

Received November 6,—Read December 12, 1872.

The researches of which an account is given in the present communication have been undertaken in continuation of those carried on by Dr. Frankland and myself at the Royal College of Chemistry, from which we arrived at the conclusion that the thickening of spectral lines was due to pressure, and not to temperature *per se**. In our joint communications we pointed out that this held good for hydrogen in Geissler's tubes and for magnesium vapour † when the spark was taken in air, by means of a method which enabled us to spectroscopically examine its various portions.

The magnesium experiment was important not only so far as the decrease of thickness of lines with decrease of density was concerned, but because it showed that one of the well-known triple lines in the spectrum of magnesium absolutely vanished altogether from the spectrum at some distance from the source of the supply of the vapour—that is, the pole of metallic magnesium. This result we also obtained, as stated in our note, when we observed the spectrum of the spark between two magnesium poles enclosed in a Geissler's tube in an atmosphere of hydrogen in which the pressure of the gas was gradually reduced.

In some experiments with sodium vapour, which were not referred to in the papers in question ‡, Dr. Frankland and myself observed the same phenomena. The experiments were conducted as follows:—

(1) Into a piece of hard glass combustion-tube, thoroughly cleaned and closed at one end, a few pieces of metallic sodium, clean and as free as possible from naphtha, were introduced. The end of the tube was then drawn out and connected with a Sprengel pump and exhausted as rapidly as possible. Hydrogen was then admitted, and the tube reexhausted and, when the pressure was again reduced to a few millimetres, carefully sealed up. The tube thus prepared was placed between the slit plate of a spectroscope and a source of light giving a continuous spectrum.

Generally, unless the atmosphere of the laboratory was very still and free from dust, the two bright D lines could be distinctly seen on the background of the bright continuous spectrum.

The tube containing the sodium was then heated with a Bunsen flame and the spectrum carefully watched. Soon after the application of the heat, a dark line thin, and delicate as a spider's thread, was observed to be slowly creeping down each of the bright sodium lines and exactly occupying the centre of each. Next, this thin black line was observed to thicken at the *top*, where the spectrum of the *lower* denser vapours was observed, and to advance downwards along the D line, until arriving at the bottom they both became black throughout; and if now the heat was still applied, thus increasing the density of the various layers of the sodium vapour, the lines began to broaden until, in spite of considerable dispersion, the two lines blended into one. The source of heat being now removed, the same changes occurred in inverse order; the broad band split into two lines, gradually the black thread alone was left, and finally that vanished, and the two bright lines were restored.

---

* Proceedings of the Royal Society, vol. xvii. p. 289.

† Ibid. vol. xviii. p. 79.

‡ This experiment was first exhibited at a Lecture given by me at the Royal Institution in May, 1869.

(2) This experiment was then varied in the following way. Some pieces of metallic sodium were introduced into a test-tube, and a long glass tube conveying coal-gas passed to the bottom, an exit for the gas being also provided at the top. The sodium was now heated and the flow of coal-gas stopped. In a short time the reversal of the D lines was complete. The gas was now admitted, and a small quantity only had passed when the black lines were reduced to threads.

In my former communications to the Royal Society I have pointed out the extreme importance of these facts in connexion with solar and stellar physics. In observing the sun by the new method, we get various Fraunhofer lines thickened in the spots and thinned in the chromosphere and prominences; and in these latter, in some instances, notably in the case of F, we find the lines gradually widening as they approach the limb of the sun.

While this may be remarked as a solar demonstration of the correctness of the conclusion at which Dr. FRANKLAND and myself had arrived, it is to be noted that bright line prominences may occasionally be seen on the sun's disk over or near spots in the spectrum of which the same lines are thick, while this phenomenon could not exist if the thickening of the lines were due to temperature alone.

Method employed.*

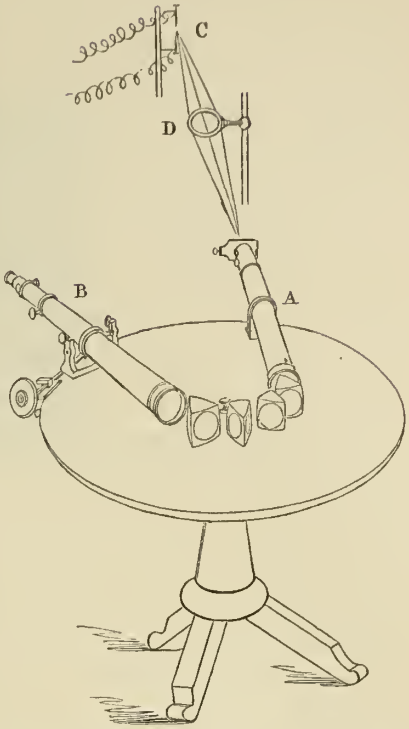
The method of observing spectra to which I have already referred, and which has been adopted in the work of which I now propose to give an account, consists in throwing an image of the spark on the slit of a spectroscope in the laboratory experiments in exactly the same manner in which I proposed, in 1866, that an image of the sun should be thrown on the slit in order to spectroscopically examine minute portions of the sun and his surrounding atmosphere.

It is obvious that in this method the image of the slit will be associated in the spectroscope with an image of a section of the spark, and that if from any cause there be various shells of vapour surrounding each pole, which shells give different spectra, then these spectra will be sorted out so that their variations may be traced from pole to pole.

---

* This method was first exhibited at a lecture at the Royal Institution, April 2nd, 1870. The same method has more recently been employed with great success by M. SALET in a research on the spectra of the metalloids.

Fig. 1.



A. Collimator. C. Spark.
B. Observing Telescope. D. Lens.

The arrangements adopted will be easily gathered from the annexed woodcut (fig. 1) and the accompanying description. It is scarcely necessary to add that an important condition of this new method is that the object-glass of the collimator should be filled with light, and also that no light should be wasted. So long as these conditions obtain, conjugate foci and different lenses may be employed and the size of the image varied at pleasure, and still the brightness of the spectrum will be sufficient.

The instruments with which the observations have been made are as follows:—

A large spectroscope, a sister instrument to that used by Bunsen and Kirchhoff in their celebrated researches, and made by the same maker, Steinheil of Munich*. It is furnished with four prisms of flint glass. Three are of an angle of 45° and one of 60°. The general arrangements of the instruments are described by Kirchhoff in his memoir.

In front of the slit plate is placed a lens throwing on the slit the image of the spark.

A coil, made by Apps and giving a 4-inch spark.

A large Leyden jar has also been occasionally used as a condenser on the secondary wire.

Beneath the observing-telescope is placed a commutator, by which the current is controlled by the observer without changing his position.

The window of my laboratory looks due south, and the collimator is placed in the same direction; and when it became necessary to have the solar spectrum in the field, the light reflected from a heliostat placed outside the laboratory in direct prolongation of the line of collimation was thrown on to the lens and thus on to the slit, where the size and intensity of the images could be varied at pleasure by altering the position of the lens.

When it was required to photograph a spectrum, the ordinary observing-telescope of the spectroscope was dismounted, and its place supplied by a telescope of $3\frac{3}{4}$ inches aperture and 49 inches focus. This was supported on the cast-iron table of the spectroscope at one end and at the other on a stand. The eyepiece and its mounting were removed, and against the end of the tube, thus left free, a small camera-box, holding a plate $4\frac{1}{4}$ in. by $3\frac{1}{4}$ in., was placed, and the photograph taken in the usual manner, the focus being obtained partly by careful observation with powerful magnifiers and partly by trial plates.

---

* This spectroscope has been temporarily placed at my disposal by Professor Guthrie, of the Royal School of Mines, to whom my best thanks are due.

From the time of WHEATSTONE'S first experiments, when in 1835 he stated that if the poles consisted of two different metals the spectrum contained the lines of both metals, down to the researches of STOKES, MILLER, and ROBINSON in 1862, there is no reference, so far as I can find, to any localization of light in any portion of the *breadth* of the spectrum. In the case of the spark taken between two poles, *e. g.* in air, the spectrum is generally one in which the lines of the two vapours and of air are blended together, all the lines running across the field.

But under certain conditions this is not so. Thus STOKES*, who used the spark itself instead of a slit, remarked that the metallic lines are "distinguished from air lines by being formed only at an almost insensible distance from the tips of the electrodes, whereas air lines would extend right across."

MILLER†, who used a slit and a spark close to it, referring to his photographs of electric spectra, remarks, "the marginal extremities of the metallic lines leave a stronger image than their central portions," and the extremities of these interrupted lines he terms "dots."

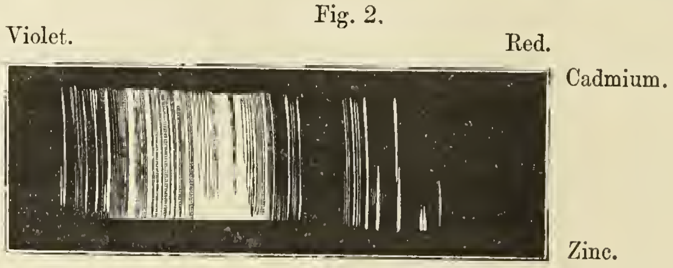
On the same subject ROBINSON‡ writes, "At that boundary of the spectrum which corresponds to the negative electrode (and in a much less degree at the positive) extremely intense lines are seen, . . . which, however, are short."

THALÉN (though he also did not adopt the method used by Dr. FRANKLAND and myself in and since 1869) observed this localization to a certain extent, doubtless on account of the long collimator which he employed.

He remarks §:—"Il y a aussi des raies brillantes qu'on n'observe que dans des cas exceptionnels, comme, par exemple, quand la quantité de la substance soumise à l'expérience est très-abondante ou quand l'incandescence devient très-vive. Ces raies qui se présentent ordinairement aux bords du spectre sous la forme de points d'aiguille, même quand les autres raies du métal forment des lignes continues en travers du spectre, ont été représentées sur la planche par des lignes très-courtes."

Before I proceed further I beg to refer to the two annexed woodcuts (figs. 2, 3), copied from photographs of a part of the spectrum observed when the jar-spark passes (1) between the poles of *zinc* and *cadmium*, and (2) between *cadmium* and *lead*, and the image is thrown on the slit. It will be seen that in the case of these metallic vapours (and it is true of

Fig. 2.



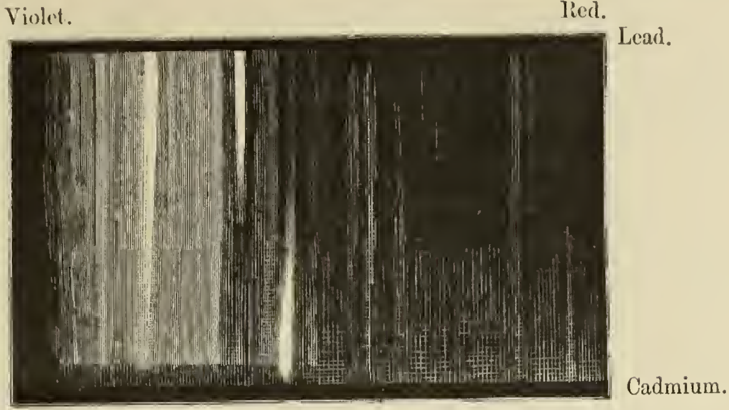
---

* Philosophical Transactions, vol. clii. 1862, p. 603. † *Op. cit.* p. 877. ‡ *Op. cit.* p. 947.

§ "Mémoire sur la détermination des longueurs d'onde des raies métalliques," p. 12, printed in the Nova Acta Regiæ Societatis Scientiarum Upsaliensis, ser. iii. vol. vi. Upsala, 1868.

all others that I have yet observed) the lines as in the before-mentioned case of the triple line (b) of magnesium, are of unequal length, and that in the new method of observation the lines in the spectra of the two metallic vapours and of the air are separated in the clearest and most convenient manner, the air lines going right across, and the lines of the metallic vapours extending to greater or less distances from each pole, and in some cases (*i. e.* of the longest lines) overlapping.

Fig. 3.



With this communication are maps (Plates XI., XII., XIII.) of the spectra of the following elements made on this method, the jar being used:—Na, Li, Mg, Al, Mn, Co, Ni, Zn, Sr, Cd, Sn, Sb, Ba, and Pb. The lines were laid down from THALÉN'S maps, given in the memoir quoted above and on the same scale, namely 2 centimetres to each $\frac{1}{1000000}$ millim. of wave-length. The spectra were then carefully and repeatedly observed, and the comparative lengths of the lines estimated and laid down over their respective wave-lengths

At the same time that these spectra have been mapped with the spark taken in air, many of them have also been observed when their metals were enclosed in tubes and subjected to a continually decreasing pressure, as in the case of the before-mentioned experiment with magnesium. *In all these experiments it was found that the longest lines invariably remained visible longest.*

In the case of zinc the effect of these circumstances was very marked, and they may be given as a sample of the phenomena generally observed. When the pressure-gauge connected with the Sprengel pump stood at from 35 to 40 millimetres, the spectrum at the part observed was normal, except that the two lines 4924 and 4911 * (both of which, when the spectrum is observed under the normal pressure, are lines with thick wings) were considerably reduced in width. On the pump being started these lines rapidly decreased in length, as did the line at 4679,—4810 and 4721 being almost unaffected; at last the two at 4924 and 4911 vanished, as did 4679, and appeared only at intervals as spots on the poles, the two 4810 and 4721 remaining little changed in length though much in brilliancy. This experiment was repeated four times, and on each occasion the gauge was found to be almost at the same point, viz.:—

* THALÉN'S scale as given by WATTS.

1st observation, when the lines 4924 and 4911 were gone the gauge stood at			. . . .	30 millimetres.
2nd	„	„	„	29 „
3rd	„	„	„	29 „
4th	„	„	„	31 „

A rise to 34 millimetres was sufficient to restore the lost lines.

Experiments with Chemical Compounds.

Since it appeared that the purest and densest vapour alone gave the greatest number of lines, or, in other words, that the truly complete spectrum of a body is alone to be obtained upon the metallic pole itself where the vapour is densest and purest, it became of interest to examine the spectrum of a compound consisting of a metal combined with a non-metallic element.

To this end a number of experiments were made, in which the metallic spectra were compared with those given by the same metals when combined with chlorine under the same conditions as in the former experiments.

The compounds thus experimented on were as follows, the jar being used:—$\mathrm{Li\ Cl}$, $\mathrm{Na\ Cl}$, $\mathrm{Mg\ Cl_2}$, $\mathrm{Zn\ Cl_2}$, $\mathrm{Sr\ Cl_2}$, $\mathrm{Cd\ Cl_2}$, $\mathrm{Ba\ Cl_2}$, $\mathrm{Pb\ Cl_2}$, and $\mathrm{Al_2\ Cl_6}$. It was found in all cases that the difference between the spectrum of the chloride and the spectrum of the metal was:—*That under the same spark-conditions the short lines were obliterated, while the air lines remained unchanged in thickness.*

Changing the spark-conditions by throwing the jar out of the circuit, this change was shown in its strongest form, the final results being that only the very longest lines in the spectrum of the metal remained.

The following are the details of the experiments made under these conditions:—

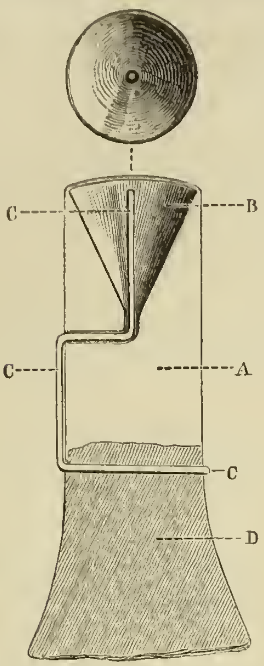
Method of Observation.—Some pieces of stout aluminium wire 10 millims. long and 3 millims. in diameter were taken; one end was flattened for about one third of the length for the purpose of inserting it in the spark-holder, and the other was drilled down in the direction of the axis for from 2 to 3 millims., and thus formed into a small conical cup; a very fine hole was then drilled through the side of this cup at the bottom and the flattened end carefully split. Through the lateral hole a piece of platinum wire 0·5 millim. in diameter was passed and one end brought round through the split end of the aluminium, while the other was brought up the centre of the cup. The split was now closed by strong pressure in a vice, and the ends of the platinum wire cut off. The whole now presented the appearance of a small candle, the platinum wire representing the wick: the accompanying figures (figs. 4, 5) will render the preceding statement clear[*]. Round this wick the chloride in fine powder was tightly rammed down. [A similar cup, without the wick, was used for the examination of the spectra of metallic barium, strontium, and lithium, the metal being hammered into it.] One of these cups with the chloride replaced the lower pole in the spark-holder, the upper one being composed of copper, that metal being selected as being a good conductor and giving a very simple and easily recognized spectrum.

---

[*] The object of the wick was to confine the spark to the centre of the dry chloride. Before it was adopted the spark was very unsteady, leaping about from side to side of the cup.

Fig. 4.

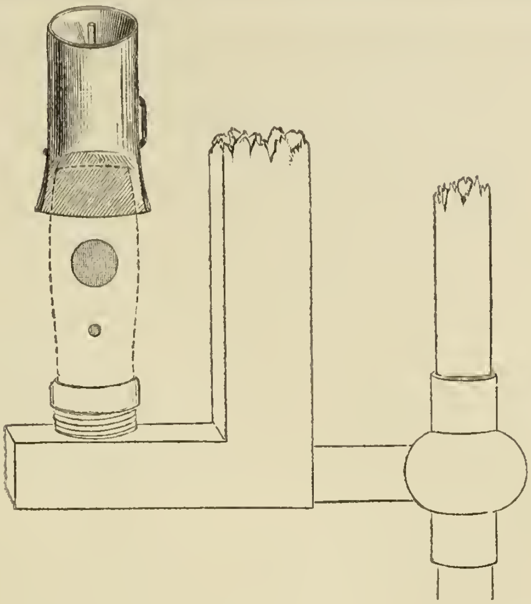
Plan and section of cup used with salts.



A. Aluminium wire.
B. Cup-shaped cavity drilled in it.
C. Platinum wire.
D. Flattened and split portion of the aluminium wire.

Fig. 5.

Aluminium cup placed in the spark-stand as in use.



Chlorides observed. Lithic Chloride, Li Cl.—The wave-lengths of the longest lines of this metal are as follows:—6705·2, 6102·0, and 4602·7, the latter (in the blue) being a wide and winged line. When the spectrum of the chloride is observed, the red line 6705·2 is seen right across the spectrum, the orange, 6102·0, is faintly visible for about half the distance; 4602·7 has vanished altogether. In the case of lithium this extinction can be carried further in the flame reaction with an ordinary Bunsen burner, in which the red line 6705·2 is alone seen*.

Sodic Chloride, Na Cl.—The D line $\left.\begin{matrix}5895{\cdot}0\\5889{\cdot}0\end{matrix}\right\}$ is by very far the longest line in the sodium spectrum; it is, in fact, the longest metallic line I have observed. After D come $\left.\begin{matrix}6160\cdot0\\6154\cdot2\end{matrix}\right\}$ in the red and $\left.\begin{matrix}5687\cdot2\\5681\cdot4\end{matrix}\right\}$ in the yellow, the latter pair having a slight advantage over the former. $\left.\begin{matrix}5154\cdot8\\5152\cdot5\end{matrix}\right\}$ come next, and the shortest is 4982·5, really a double line, but so nebulous and ill-defined that THALÉN has represented it as single. In the chloride we find D $\left.\begin{matrix}5895\cdot0\\5889\cdot0\end{matrix}\right\}$ all across the spectrum, and all the others have vanished but a trace of $\left.\begin{matrix}5687\cdot2\\5681\cdot4\end{matrix}\right\}$.

---

* It is necessary in dealing with Li Cl and Na Cl to have the poles rather far apart (8 to 10 millims.), as, on account of the easy volatility of these chlorides, if the poles are close all the lines appear stretching across the spectrum.

Magnesic Chloride, $Mg\ Cl_2$.—Magnesium has three lines (b) surpassing all the others in length; their wave-lengths are 5183·0, 5172·0, and 5166·7: these lines alone are constant in the chloride; 4481·0, the winged line, sometimes flashes in.

Zincic Chloride, $Zn\ Cl_2$.—Zinc has three long lines in the blue, 4809·7, 4721·4, 4679·5; these only are visible in the spectrum of the chloride. One line, 6362·5, in the extreme orange, is of the same length, apparently, as the shortest of the three blue lines, but is not visible, possibly on account of its faintness.

Strontic Chloride, $Sr\ Cl_2$.—Strontium has one extremely long line, 4607·5, and this with two in the indigo, 4226·3 and 4215·3, next in length to it, are alone seen in the chloride spectrum.

Cadmic Chloride, $Cd\ Cl_2$.—Cadmium, like zinc, has three lines of greater length than all the rest—one in the blue-green, 5085·0, and two, 4799·0 and 4676·8, in the blue. These alone appear in the spectrum of the chloride.

Plumbic Chloride, $Pb\ Cl_2$.—Lead has its longest line, 4058·0, in the violet; this line alone is visible in the chloride spectrum; 5607·0 in the yellow-green, which appears nearly as long, is not visible.

Baric Chloride, $Ba\ Cl_2$.—Barium has three lines, distinguished by their great length; they are 5534·5 in the yellow-green, 4933·4 in the green, and 4553·4 in the indigo. These only are visible in the chloride spectrum.

Aluminic Chloride, $Al_2\ Cl_6$.—Aluminium has but two long lines, which fall between H_1 and H_2, and are of the following wave-lengths, 3961·0 and 3943·0; these alone are visible in the spectrum of aluminic chloride.

It will be seen from the foregoing that in the case of elements with low atomic weights, combined with one equivalent of chlorine, the number of lines which remain in the chloride is large—over 60 per cent., for instance, in the case of Li, and 40 per cent. in that of Na. While, on the other hand, in the case of elements with greater atomic weights, combined with two equivalents of chlorine, we get a much smaller number of lines remaining—8 per cent., for instance, in the case of Ba, and 3 per cent. in the case of Pb.

Preliminary Experiments with Mechanical Mixtures.

Another series of experiments has had for its object the examination of the spectrum of mechanically mixed metals—alloys prepared *ad hoc*. These experiments, which at present are preliminary only, were made because it seemed clear that the same law that was observed with the chlorides should hold good.

A cursory examination of the spectra of some amalgams of tin and magnesium has shown that this is the case.

For instance, it is possible to begin with an alloy which shall only give us the longest line or lines in the spectrum of the smallest constituent, and by increasing the quantity of this constituent the other lines can be introduced in the order of their length. This reaction is so delicate that I learnt from it a thing I had not before observed, that the least refrangible line of *b*, the triple line of magnesium, is really a little longer than its more refrangible companion; for the spectrum of magnesium was reduced to this one line in an alloy in which special precautions had been taken to introduce the minimum of magnesium.

It follows from this statement that not only is the spectrum-analysis almost infinitely more delicate than it has hitherto been supposed to be in the case of the elements in which the difference between the longest and shortest lines is least*, but that in time it may become quantitative; for if the admixture of certain other bodies extinguishes the shorter lines of metallic spectra, it would seem that a series of carefully executed maps of the spectra of alloys, the proportions of the constituents of which are known, will place in our hands the means of determining (roughly it is true) by mere inspection the quantity of the sought metal present in an alloy, the composition of which *quâ* that metal is unknown. At the same time it is clear that further progress must be made before such a method can be practically employed in the arts.

Although the working hypothesis which has suggested the various lines of research which have been followed is, I think, sufficiently clear, I refrain from dwelling upon it until other researches now in progress enable me more fully to judge of its value, and to state at greater length the various conclusions which may be drawn from it.

Application of these Observations to the Solar Spectrum.

These observations have an important bearing upon the solar spectrum, for the reason that, as is well known, all the lines known to exist in the spectrum of an element supposed to be present in the sun's atmosphere are not in all cases reversed.

Before I proceed to give the facts in detail it will be well to go over the prior work of KIRCHHOFF and ÅNGSTRÖM, to see precisely the evidence on which our present knowledge of the elements in the solar atmosphere, as determined by KIRCHHOFF's method of solar observation (that is, the non-localization or integration of the various solar regions, such as spots, faculæ and chromosphere), rests.

KIRCHHOFF, in his paper referring to FRAUNHOFER's prior determination of the double line D being coincident with a double line observed in the spectrum of sodium vapour, locates sodium vapour in the solar atmosphere, as Professor STOKES had done before him.

---

* The great lengths of the lines of sodium, lithium, &c. at once account for the delicacy of their spectrum reactions.

Coincident with all the bright iron lines which he observed with the spark he used (he only saw a small number of the lines), he found well-defined Fraunhofer lines. He therefore located iron vapour in the atmosphere. The rest of the evidence relating to other metals I give from the translation of his memoir by Professor Roscoe*.

"As soon as the presence of one terrestrial element in the solar atmosphere was thus determined, and thereby the existence of a large number of Fraunhofer lines explained, it seemed reasonable to suppose that other terrestrial bodies occur there, and that, by exerting their absorptive power, they may cause the production of other Fraunhofer lines; for it is very probable that elementary bodies which occur in large quantities on the earth, and are likewise distinguished by special bright lines in their spectra, will, like iron, be visible in the solar atmosphere. This is found to be the case with calcium, magnesium, and sodium. The number of the bright lines in the spectrum of each of these metals is indeed small; but those lines, as well as the dark ones in the solar spectrum with which they coincide, are so uncommonly distinct that the coincidence can be observed with very great accuracy.

"In addition to this, the circumstance that these lines occur in groups renders the observation of the coincidence of these spectra more exact than is the case with those composed of single lines. The lines produced by chromium also form a very characteristic group, which likewise coincides with a remarkable group of Fraunhofer lines; hence I believe that I am justified in affirming the presence of chromium in the solar atmosphere. It appeared of great interest to determine whether the solar atmosphere contains nickel and cobalt, elements which invariably accompany iron in meteoric masses. The spectra of these metals, like that of iron, are distinguished by the large number of their lines; but the lines of nickel, and still more those of cobalt, are much less bright than the iron lines, and I was therefore unable to observe their position with the same accuracy with which I determined the position of the iron lines. All the *brighter lines* of nickel appear to coincide with dark solar lines; the same was observed with respect to some of the cobalt lines†, *but was not seen to be the case with other equally bright lines of this metal.* From my observations I consider that I am entitled to conclude that nickel is visible in the solar atmosphere; I do not, however, yet express an opinion as to the presence of cobalt. Barium, copper, and zinc appear to be present in the solar atmosphere, but only in small quantities; the brightest of the lines of these metals correspond to distinct lines in the solar spectrum, but the weaker lines are not noticeable. The remaining metals which I have examined, viz. gold, silver, mercury, aluminium, cadmium, tin, lead, antimony, arsenic, strontium, and lithium, are, according to my observations, not visible in the solar atmosphere. Through the kindness of M. Grandeau, of Paris, I obtained several pieces of fused silicium; I was thus enabled, by using them as electrodes, to examine the spectrum of this element. The lines in the silicium spectrum are, however, with the exception of two broad green bands at 1810 and 1830, so deficient in luminosity that I was unable to determine their position with sufficient accuracy to reproduce them in my drawing. The two bright green bands do not correspond to dark bands in the solar spectrum ; so that, as far as I have been able to determine, silicium is not visible in the solar atmosphere."

---

* Transactions of Berlin Academy, 1861. Translated by Roscoe. Macmillan.

† The italics are mine.

It will be seen from the foregoing that Kirchhoff dealt mainly with the brightest lines, although the test failed him in the case of cobalt, for a reason I shall show further on. Hence, as a result of Kirchhoff's work, we have in the solar atmosphere :—

Present.	*Doubtful.*	*Absent.*
Sodium.	Cobalt.	Gold.
Iron.		Silver.
Calcium.		Mercury.
Magnesium.		Aluminium.
Nickel.		Cadmium.
Barium.		Tin.
Copper.		Lead.
Zinc.		Antimony.
		Arsenic.
		Strontium.
		Lithium.
		Silicium.

Ångström* gives no list such as this, but in its place a table of coincidences observed. Thalén, his associate, in a separate memoir†, gives, however, as present in the sun :—

Sodium,
Iron,
Calcium,
Magnesium,
Chromium,
Nickel,
Cobalt,
Hydrogen,
Manganese,
Titanium,

thus rejecting zinc and barium from Kirchhoff's list of accepted elements, adding cobalt from the doubtful list, and hydrogen and manganese from Ångström's, and titanium from his own observations.

The table of coincidences referred to and Ångström's remarks thereon explain the cause of this. Kirchhoff's evidence for zinc had depended upon the coincidence of two lines only, and these were doubtless thought insufficient, as in the cases of the metals retained in the list the number of the coincidences was much greater, viz. :—

Sodium . . .	9 (all)	Magnesium . .	4 (3 ?)
Iron	450	Chromium . .	18
Calcium . . .	75	Nickel . . .	33
Cobalt . . .	19	Hydrogen . .	4 (all)
Manganese . .	57	Titanium . . .	118

---

* Recherches sur le spectre solaire, par A. J. Ångström. Spectre normal du Soleil. Berlin, 1869.

† Longueurs d'onde des raies métalliques, p. 11. Nova Acta. Upsala, 1868.

*Barium . . .	11 (of 26)	Zinc	2 ? (of 27)
Aluminium . .	2 ? (of 14)		

From ÅNGSTRÖM's remarks, which I proceed to give, it is evident that he was not quite satisfied with the brilliancy test relied on by KIRCHHOFF, and that his doubts concerning zinc arose from this cause.

"L'aluminium possède certainement des raies brillantes en plusieurs endroits du spectre, mais les raies situées entre les deux H sont les seuls qui semblent coïncider avec les lignes Fraunhofériennes. Pour expliquer ce phénomène singulier il faut dire que les raies violettes se présentent comme les plus fortes dans le spectre de ce métal. De même que les raies jaunes du sodium, ces deux raies d'aluminium ont fait voir quelquefois le phénomène d'absorption consistant en ce qu'une raie noire se présente dans le milieu de chacune d'elles, ce qui prouve la forte intensité des dites raies. En observant les rayons extra-violettes de ce métal, on décidera si les deux raies mentionnées ci-dessus coïncident ou non avec des raies Fraunhofériennes; car si ma supposition est vraie, les raies extra-violettes doivent coïncider aussi avec les lignes obscures du spectre solaire.

"A deux raies du zinc que j'ai indiquées sur mes planches comme coïncidant avec des raies Fraunhofériennes il en faut ajouter une troisième, située à 4809·7; mais, à l'égard des deux raies, très-larges et très-fortes, d'une apparence nébuleuse, il n'y a pas de correspondance visible; ainsi, la présence du zinc dans le soleil me semble très-douteuse. Je dirai cependant qu'il existe trois raies de magnesium, du même aspect nébuleux, qui ne possèdent pas non plus de correspondance avec les raies de FRAUNHOFER, quoique la présence de ce corps dans le soleil ne permettre pas le moindre doute"†.

In the accompanying maps the lines of certain metallic vapours reversed in the solar spectrum are given under the spectrum mapped by the new method. *It will be seen that invariably the reversed lines are simply those which are longest in the spectrum.*

It is not necessary on the present occasion to dwell upon the great importance of this determination, both in connexion with the fact just stated and the other facts touching the lines which remain longest in chemical combinations‡ and mechanical mixtures. It supplies us at once with the true test to apply to the reversal of solar lines, and a guide of the highest value in spectrum observations of the chromosphere and photosphere. It is one, doubtless, which will shortly enable us to determine the presence of new materials in the solar atmosphere, and it is seen at once that to the last published table of solar elements (that of THALÉN) must be added, zinc, aluminium, and possibly strontium § as a result of the application of the new test.

---

* I include this "below the line," though I cannot but think that its omission by THALÉN was accidental.

† It will be seen from my maps that this statement is not accurate. THALÉN's later work left only one line doubtful.

‡ A. MITSCHERLICH has noted the disappearance of certain lines in consequence of the presence of several substances in the same flame, but he only applies this to the sun by supposing the substances to be combined and so not to give a spectrum (Ann. de Chim. et de Phys. 3 sér. vol. lxix. p. 176).

§ Barium also, if a *lapsus calami* has not been made.

In the case of the chromosphere, the observation of the order of lengths of the bright lines is invested with a new importance, as also the observation of lines which are not reversed in the ordinary solar spectrum. As an instance of this, I may state that the fact that the re-reversal into brightness in the chromosphere of the line 1474 K is not due to iron vapour, is settled by the other fact, which this new method has enabled me to determine, that the coincident line in the iron spectrum is one of the shortest lines in the whole spectrum.

In the case of the photosphere, not only may we hope to account for such cyclical changes as I have long had reason to suspect and have referred to in prior communications to the Society, but it is essential that spot-spectra shall be photographed with special reference to the consideration that in such spectra the new lines may now be found in all probability, to be those which are only slightly shorter than those ordinarily reversed. This research I am making arrangements to carry on.

It will be observed that in the maps the elements are arranged in the order of their atomic weights. This was done before all the comparisons were made, because, as I have before announced to the Royal Society in the case of several of the elements, the length of the lines in the spectra of the vapours observed in the chromosphere are also most frequently arranged in this order, as predicted by Mr. STONEY*. The comparison rendered possible by the maps also bears out this view with regard to the outer layers; for in the case of H and Na all the lines are reversed; in the case of Mg, about which there was a doubt in ÅNGSTRÖM'S observations, only one line is possibly dropped, and this is not certain. When we come, however, to the elements with higher atomic weights the number of lines reversed is less. But the maps also show that when once the higher layers of the chromosphere, where less constant action goes on, are passed, atomic weight ceases to be a guide, and we are therefore driven to other considerations, which promise to largely increase our knowledge of the kind of action at work in the solar atmosphere and the cyclical variation of that action.

The Maps which accompany this communication have been made by my assistant, Mr. R. J. FRISWELL. They have only been revised by myself. I am anxious to take this opportunity of testifying to the zeal and ability he has displayed in a research necessarily very tedious from its character, and requiring great patience and care.

---

* This arrangement has since been broken up for the convenience of the engraver. Some of the spectra having both sun and chloride lines had to be displaced by others without these, in order to get the whole of the maps on to the three Plates.

NOTES TO THE MAPS[*].

The lengths of the lines are given only in reference to those of the same element; no relation is intended to be indicated between the lines of the various spectra as represented on the Maps. The lengths of the lines of one spectrum as compared with another are liable to great variation—the lines of barium being, for instance, considerably longer than those of zinc, though they are represented as of the same length on the Maps.

The poles were also much further apart in some cases than in others. In the case of barium, for instance, unless the poles were widely separated all the lines would have stretched across the spectrum, while in the case of manganese or nickel, unless the poles were close, no spectrum would be produced. The widths of the winged lines are mere approximations to the relative widths of the lines of the particular spectrum to which they belong, the width of a line in one map only relating to the lines of that map. No comparison can hence be made between widths given in different maps.

Nor must the widths assigned to the lines be regarded as true; they have been purposely exaggerated. For instance, wings of the lines 4924 and 4911 (zinc) cover a length of 8 millims., equivalent on the scale to $\frac{40}{10,000,000}$[†] millim.; but it is not intended to assert that the wings extend over so large a space.

PLATE XI. STRIP II.—LITHIUM.

Wave-length.	Length.	Whether reversed in the Solar Spectrum.	Whether in the Spark-Spectrum of the Chloride.	Remarks.
6705·2 6102·0	4 4	Not in Sun.	Present.	These lines invariably stretch across the spectrum when metallic lithium is used as the electrode.
4602·7	1		,,	This line is nebulous but brilliant; it is much shorter than either of the others.

PLATE XI. STRIP III.—SODIUM.

6160·0 6154·2	3	Reversed.	Not present.	THALÉN has represented these lines as extending across the spectrum and longer than 5687·2, 5681·4; but this is not the case.
5895·0 5889·0	4	,,	Present.	The D lines of the solar spectrum; their tops have never been seen, as they invariably stretch from pole to pole.
5687·2 5681·4	3	,,	,,	These lines are slightly longer than those at 6160·0 and 6154·2.
5154·8 5152·5	1	,,	Not present.	These lines are very short and faint.

---

[*] Added during the printing of the paper.

[†] Four one-millionths or forty ten-millionths of a millimetre.

PLATE XI. STRIP III.—SODIUM (continued).

Wave-length.	Length.	Whether reversed in the Solar Spectrum.	Whether in the Spark-Spectrum of the Chloride.	Remarks.
4982·5	1	Reversed.	Not present.	This is really a close pair of lines, represented by THALÉN as a single nebulous line in the map attached to his 'Mémoire sur les longueurs d'onde des raies brillantes des Métaux,' but correctly given by him as double in the maps in ÅNGSTRÖM'S memoir on the solar spectrum. The wave-length here given is the mean of the true positions, which are 4983·2 and 4981·9 respectively. The line, though nebulous, is easily divided, and is so represented on the Map.

PLATE XI. STRIP IV.—MAGNESIUM.

Wave-length.	Length.	Whether reversed in the Solar Spectrum.	Whether in the Spark-Spectrum of the Chloride.	Remarks.
5527·4	3	Reversed.	Not present.	
5183·0	4	,,	Present.	b_1. This is the longest magnesium line.
5172·0	4	,,	,,	b_2. This is slightly shorter than b_1.
5166·7	4	,,	,,	b_3. Slightly shorter than b_2.
4703·5	2	?	Not present.	There is a line coincident with this in KIRCHHOFF'S map of the solar spectrum, but it has been dropped out in ÅNGSTRÖM'S.
4586·5	. . . . . .	Reversed.	,,	I have never succeeded in observing this line, though very many attempts have been made; it is represented in the solar spectrum by ÅNGSTRÖM as an excessively faint line; and KIRCHHOFF makes it not really coincident but partly overlapping the solar line.
4481·0	1	,,	,,	This is a very brilliant winged line, but it appears short. THALÉN makes it of the same intensity as the two at 4703·5 and 4586·5; but while this is excessively bright to me, 4703·5 is faint and 4586·5 invisible. KIRCHHOFF represents it in the solar spectrum by a very much broader line than ÅNGSTRÖM does.

PLATE XI. STRIP V.—COBALT.

Wave-length.	Length.	Whether reversed in the Solar Spectrum.	Whether in the Spark-Spectrum of the Chloride.	Remarks.
6142·5	2	Not reversed.	Chloride not observed.	
6121·2	2	,,		
6003·5	. . . . . .	,,		This line could not be identified.
5482·4	4	Reversed.		This line is represented in the solar spectrum, but is not named in ÅNGSTRÖM'S map.
5452·0	2	Not reversed.		
5443·0	2	,,		
5368·0	2	,,		
5362·5	2	,,		
5359·5	2	,,		
5352·4	4	Reversed.		
5351·2	4	,,		
5342·6	4	,,		
5342·1	4	,,		

PLATE XI. STRIP V.—COBALT (continued).

Wave-length.	Length.	Whether reversed in the Solar Spectrum.	Whether in the Spark-Spectrum of the Chloride.	Remarks.
5279·6	4	Reversed.	Chloride not observed.	
5267·2	4	„		
5265·8	4	„		
5234·4	4	„		
5230·0	2	Not reversed.		This line is slightly shorter than the others to which the number 2 is assigned.
5212·0	3	„		
4867·0	4	Reversed.		These lines are a little shorter than the others marked 4, and would drop out of the solar spectrum first should a diminution of the thickness of the reversing layer occur.
4839·0	4	„		
4813·5	2	Not reversed.		
4791·7	4	Reversed.		This line is also a little shorter than the others marked 4. See remarks on 4867·0 and 4839·0 above.
4778·7	4	„		
4748·5	......	Not reversed.		This line could not be identified.
4580·8	2	„		This line is coincident with a calcium line, and also with one of iron; in calcium it is long and rather faint (intensity 4, THALÉN); in cobalt it is short and faint (intensity 4, THALÉN); in iron its intensity is unknown.
4530·5	4	Reversed.		

PLATE XII. STRIP I.—NICKEL.

6175·7	3	Reversed.	Chloride not observed.	
6115·3	2	„		
6107·5	2	„		
5892·0	2	„		
5856·5	2	„		
5475·9	4	„		
5175·6	2	„		
5168·3	2	„		
5155·1	2	„		
5145·7	2	„		
5142·0	2	„		
5136·8	2	„		
5114·9	2	„		
5099·7	3	„		
5098·5	3	„		
5080·6	3	„		
5079·7	3	„		
5034·6	2	„		
5016·5	2	„		
4983·3	2	„		
4979·6	2	„		
4935·1	3	„		
4917·6	1	Not reversed.		
4903·9	3	Reversed.		
4872·9	1	Not reversed.		
4865·3	2	Reversed.		
4854·7	3	„		
4830·2	2	„		
4828·4	2	„		
4785·8	2	„		
4755·0	3	„		
4713·7	4	„		
4647·0	3	„		
4401·7	4	„		

Plate XII. Strip II.—ALUMINIUM.

Wave-length.	Length.	Whether reversed in the Solar Spectrum.	Whether in the Spark-Spectrum of the Chloride.	Remarks.
6371·0	. . . . . .	Not reversed.	Not present.	Not identified.
6344·5	. . . . . .	„	„	Not identified.
6244·0	2	„	„	Wide and nebulous.
6234·0	2			
5722·5	1	„	„	
5695·5	1	„	„	
5592·5	1	„	„	
5056·5	1	„	„	
4662·0	1	„	„	
4529·5	1	„	„	
4511·0	1	„	„	
4478·5	2	„	„	
3961·0	4	Reversed.	Present.	These lines appear to be slightly enlarged at the base; but as a wide slit is required to observe them, the widening has not been represented in the Map.
3943·0	4			

Plate XII. Strip III.—LEAD.

6656·0	3	Not in sun, according to Ångström's Map.	Not present.	
6452·0	2·5		„	
6059·0	1·5		„	
6040·0	2·5		„	
6009·0	1		„	Winged.
6001·5	2		„	„
5895·0	2		„	
5874·0	1		„	
5856·5	1		„	Winged.
5779·0	1		„	
5607·0	4		Present.	Winged. Next to longest line.
5546·0	3		Not present.	„ „ „ „
5523·5	2		„	
5372·0	3		„	Winged.
5274·5	1		„	
5206·5	1		„	
5201·0	1		„	
5189·0	1		„	
5163·0	1·5		„	Winged; very wide and brilliant.
5045·0	1		„	
5004·5	1		„	
4802·0	0·5		„	
4796·5	0·5		„	
4760·0	0·5		„	
4573·0	?		„	This line is very short, faint, and nebulous. It has been omitted from the Map.
4401·5	0·5		„	Winged; almost concealed by the wings of 4386·5.
4386·5	2		„	Winged; very wide and conspicuous.
4246·0	2			
4167·5	1		„	Winged; wide.
4062·5	4		„	This line is faint and difficult to observe.
4058·0	4		Present.	Longest line.

PLATE XII. STRIP IV.—MANGANESE.

Wave-length.	Length.	Whether reversed in the Solar Spectrum.	Whether in the Spark-Spectrum of the Chloride.	Remarks.
6020·7	4	Reversed.	Not observed.	
6015·6	4	„		
6012·5	4	„		
5515·6	4	„		
5443·0	3	Not reversed.		This line has the appearance of being winged more on the less refrangible side than on the other. It falls in a place where there is much glare; and it is probable that a greater dispersive power than was used would break up the supposed wing into lines. It has been accidentally shown as reversed on the Map.
5419·5	4	Reversed.		
5412·4	4	„		
5406·5	4	„		
5399·6	4	„		
5393·5	4	„		
5376·6	4	„		
5359·0	. . . . . .	Not reversed.		Not seen; could not be found.
5340·2	4	Reversed.		
5254·1	4	„		
5233·6	4	„		
5195·2	4	„		
4822·8	4	„		
4782·6	4	„		
4765·8	4	„		Drawn as one line on map, but seen as two.
4764·7	4			
4761·5	4	„		Drawn as one line on map, but seen as two.
4760·7	4			
4753·4	4	„		
4738·0	1	Not reversed.		This line is much shorter than its companions.
4729·0	3	Reversed.		In Ångström's solar spectrum there is a line at 4729·0, but the manganese line beneath is shifted slightly to the left, its position being 4728·9. This is evidently an engraver's error. This line and 4726·0 are represented as one line.
4726·0	?	Not reversed.		
4708·7	4	Reversed.		
4503·5	3			
4501·2	3			
4498·2	3	„		All these lines appear in close masses, and it has not been possible to represent them on the scale of the map. There are also several discrepancies here between Ångström and Thalén.
4495·2	3			
4491·0	3			
4489·5	3			
4478·9	2			
4472·4	2			
4470·5	2			
4464·0	2			
4461·5	3			
4461·0				
4459·8	3			
4457·7	3			
4457·3				
4457·0				
4456·2				
4455·5	3			
4455·2				
4452·0	?	Not reversed.		This line is not reversed in the sun, but, owing to the closeness of the lines and complication of the spectrum, it was not possible to observe its length. There are 9 lines falling between 4459·8 and 4450·4, and with the dispersion used these lines appear as a mass. The lengths given in the Map, however, represent the contour of the top of the mass, and the line has been brought up to this.

PLATE XII. STRIP IV.—MANGANESE* (continued).

Wave-length.	Length.	Whether reversed in the Solar Spectrum.	Whether in the Spark-Spectrum of the Chloride.	Remarks.
4450·4	3	Reversed.	Not observed.	
4436·4	3	”		
4435·3	3	”		
4414·7	3	”		
4280·5	3	”		
4265·0	3	”		
4258·2	3	”		
4234·8	3	”		ÅNGSTRÖM represents this line as not absolutely coincident with a solar line which lies close to it. The Mn line is placed at about 4235·0, and the solar line 4234·7; the position given by THALÉN is nearly the mean of these two. From its length we must conclude that it is reversed, and that the slight discrepancies between THALÉN in his metallic spectra and in the map of the solar spectrum appended to ÅNGSTRÖM'S memoir is accidental.
4227·0	4	”		THALÉN makes this very thin; it is, however, bright and strong.
4083·5	3	”		Seen as one.
4083·0				
4079·6	3	”		
4062·9	2	”		
4054·4	2	”		
4048·1	2	”		
4040·5	3	”		
4033·9	3	”		Seen as one.
4032·8				
4031·7	3	”		
4029·4	3	”		
3988·0	3	”		

PLATE XII. STRIP V.—CADMIUM.

6466·0	1	Not reversed.	Not present.	Winged.
6438·0	2	”	”	
6056·5	1	”	”	
6003·5	1	”	”	
5957·5	1	”	”	
5913·0	1	”	”	
5790·0	1	”	”	
5687·0	1	”	”	
5489·0	1	”	”	
5471·0	1	”	”	
5378·0	3	”	”	These lines are very broad and winged.
5337·5	3	”		
5304·5	1	”	”	
5153·0	1	”	”	
5085·0	4	” ?	Present.	Longest lines. The least refrangible is the longest of these three.
4799·0	4	” ?	”	
4676·8	4	” ?	”	
4415·5	3	”	”	

---

* The spectrum of Manganese requires much further investigation. This Table must be regarded as provisional only.

Plate XIII. Strip I.—TIN.

Wave-length.	Length.	Whether reversed in the Solar Spectrum.	Whether in the Spark-Spectrum of the Chloride.	Remarks.
6452·0	3	Not in Sun.	Not observed.	Winged.
5893·0	......			Thalén gives a line here in his map, but not in his list. It could not be identified.
5798·0	3			
5630·0	4			Longest tin line; it is faint, but well defined.
5588·5	3			Winged.
5562·5	3			"
5368·5	1			"
5347·5	1			"
5332·0	3			"
5289·5	1			"
5224·0	2			"
5100·5	2			"
5021·0	1			"
4923·0	1			"
4858·0	2			"
4584·5	1			"
4524·0	4			Next to the longest, well defined and bright.

Plate XIII. Strip II.—ZINC.

6362·5	4	Not reversed.	Not present.	This line was in the sun in Kirchhoff's time, but has now dropped out; its number on Kirchhoff's map is 771·7.
6102·0	1	"	"	Winged.
6022·5	1	"	"	"
5893·5	2	"	"	
5816·0	2	"	"	
5756·0	1	"	"	
5745·0	1	"	"	
5608·0	......	"	"	Not identified.
5577·5	1	"	"	
5563·0	1	"	"	
5465·5	......	"	"	Not identified.
5436·0	1	"	"	
5336·0	1	"	"	
5249·5	1	"	"	
5233·0	1	"	"	
5158·5	1	"	"	
5121·0	1	"	"	
5074·0	1	"	"	
5048·0	1	"	"	
4971·0	1	"	"	
4923·8	3	"	"	} Winged.
4911·2	3	"	"	
4878·0	1	"	"	
4865·0	1	"	"	
4809·7	4	Reversed.	Present.	Longest zinc line.
4721·4	4	"	"	Second longest.
4679·5	4	"	"	Third longest. Same length, apparently, as 6362·5, but it is really longer, for it remains in the sun, while 6362·5 has dropped out since Kirchhoff's time.

Plate XIII. Strip III.—STRONTIUM.

Wave-length.	Length.	Whether reversed in the Solar Spectrum.	Whether in the Spark-Spectrum of the Chloride.	Remarks.
6550·0	2	Not reversed.	Not present.	
6501·5	2		”	
6407·0	1		”	
6387·0	2		”	
6380·0	2		”	
5970·5	2		”	
5850·0	2		”	
5540·0	2		”	
5533·5	2		”	
5522·5	2		”	
5503·5	2		”	
5485·0	1		”	
5480·0	2		”	
5256·0	1		”	
5238·5	1		”	
5228·5	1		”	
5225·5	1		”	
5223·5	1		”	
4967·5	1		”	
4961·5	1		”	
4876·0	1		”	
4872·0	1		”	
4831·5	1		”	
4812·0	1		”	
4783·5	1		”	
4740·5	1		”	
4721·0	1		”	
4607·5	4	?	Present.	This is the very longest Sr line, and in Hoffmann's continuation of Kirchhoff's maps two solar lines fall within the boundary of it, which is wide. One of these now remains, and is the calcium line 4606·5*; the other was probably this Sr line: the numbers in Hoffmann's continuation are 2386·0 and 2386·4; the position of the centre of the forked extremity of the Sr line would be about 2386·2.
4305·3	2	Not reversed.		
4226·3	3	Coincident with solar Ca line.	”	Coincident with the longest Ca line; this line probably belongs really to calcium.
4215·3	4	Coincident with solar Ca line.	”	Coincident with another Ca line whose length is unknown.
4161·0	2	Not reversed.	Not present.	
4078·5	4	?	”	Not reversed in Ångström's Map.

---

* So given in Ångström's Map, but Thalén in his list makes the calcium line and that of strontium absolutely coincident at 4607·5.

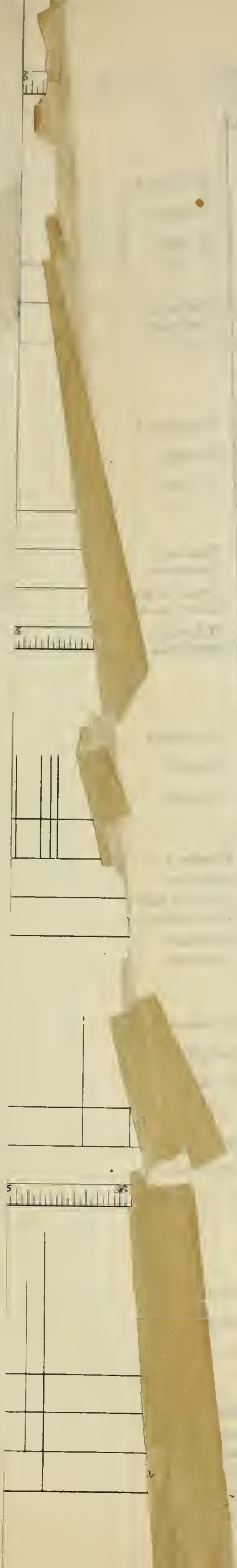
Plate XIII. Strip IV.—ANTIMONY.

Wave-length.	Length.	Whether reversed in the Solar Spectrum.	Whether in the Spark-Spectrum of the Chloride.	Remarks.
6301·5	1	Not in Sun.	Not observed.	
6244·5	2			
6209·0	2			
6193·0	2			
6155·0	2			
6128·5	4			
6078·0	4			
6051·0	2			
6003·5	4			Winged.
5979·5	2			
5909·0	3			Winged.
5893·5	3			
5791·5	3			
5638·0	2			
5607·0	2			
5567·0	2			
5463·5	......			Not identified.
5379·0	......			
5371·5	......			
5352·5	......			
5241·5	......			
5208·0	......			
5177·0	......			
5141·0	2			Winged.
5112·5	2			
5036·0	2			
4948·5	2			
4877·5	2			
4835·0	2			
4786·0	2			
4734·5	2			
4711·0	2			
4691·0	2			
4591·5	1			Winged.
4352·0	1			
4265·0	1			Winged ; a little longer than the two preceding lines.

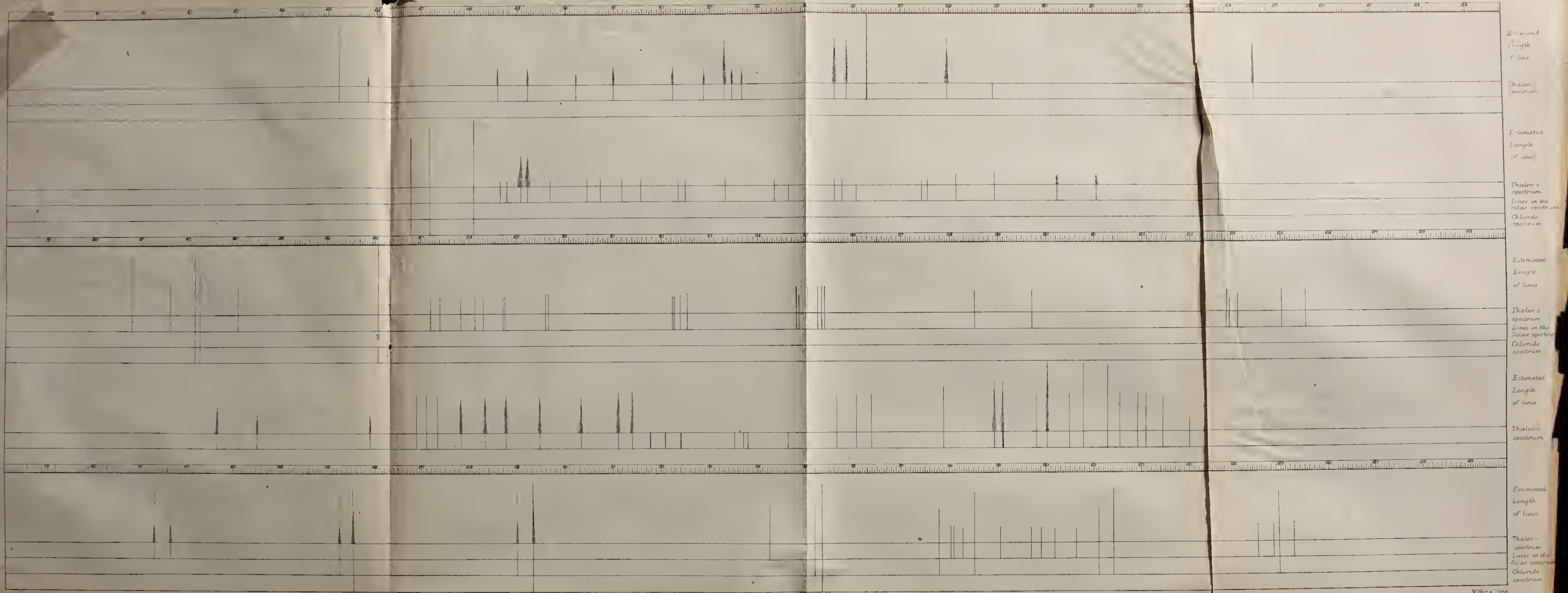
Plate XIII. Strip V.—BARIUM.

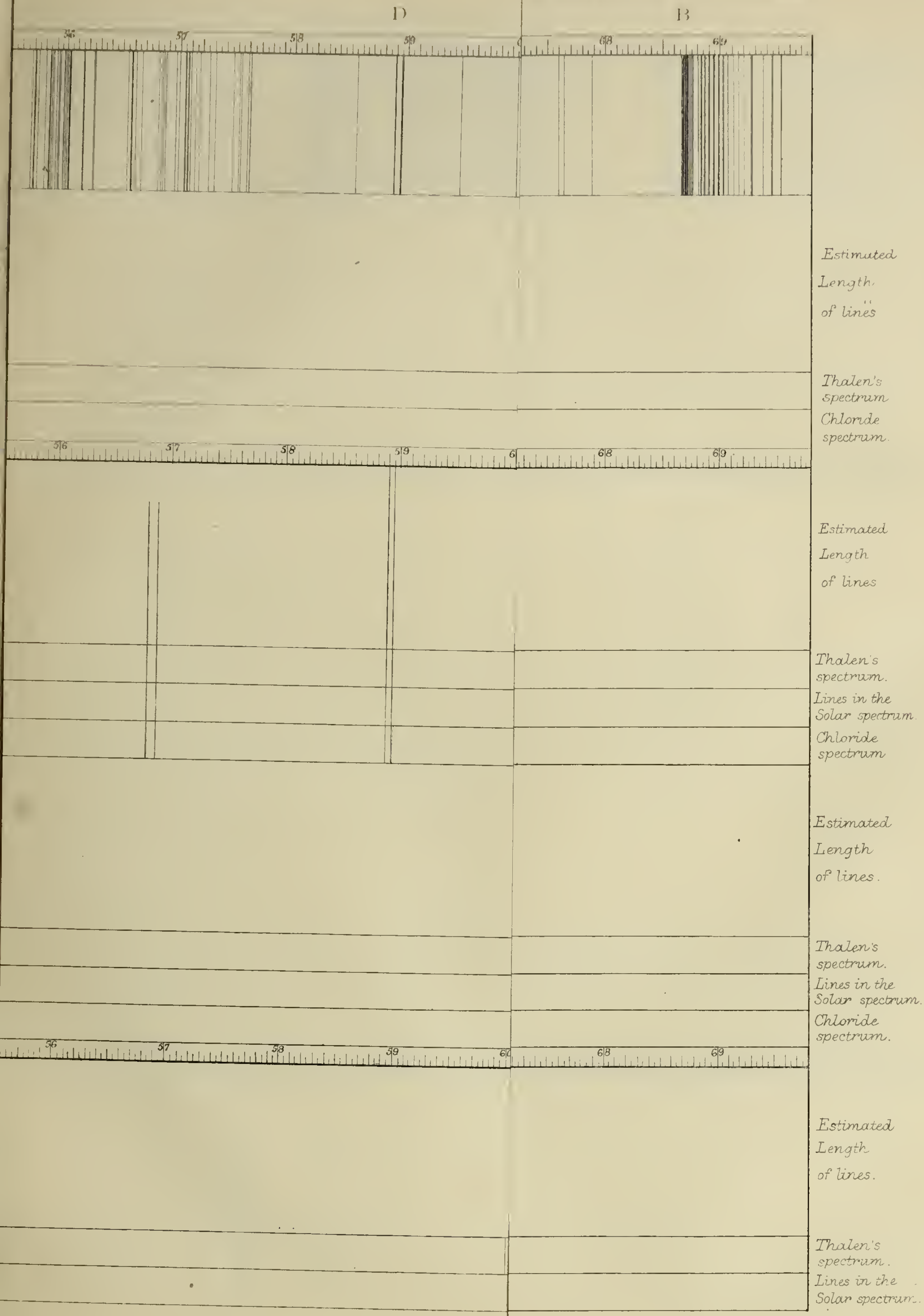
Wave-length.	Length.	Whether reversed in the Solar Spectrum.	Whether in the Spark-Spectrum of the Chloride.	Remarks.
6526·0	1	Not reversed.	Not present.	
6496·0	4	Reversed.	,,	
6483·0	3	,,	,,	Accidentally omitted from solar strip in the Map and made too short.
6449·0	1	?	,,	Coincident with a reversed calcium line.
6343·0	1	?	,,	There is a line at 6343·2 in Ångström's map, but this is too short for reversal.
6140·6	4	Reversed.	,,	
6109·9	3	,,	,,	
6062·0	1	Not reversed.	,,	
6018·0	1	,,	,,	
5991·5	1	,,	,,	
5971·0	1	,,	,,	
5904·5	1	?	,,	Coincident with a faint iron line.
5852·5	4	Reversed.	,,	
5827·0	1	Not reversed.	,,	
5808·5	1	?	,,	Coincident with two iron lines reversed in the sun.
5803·5	1			
5779·5	3	Reversed.	,,	
5534·5	4	,,	Present.	This appears to be the longest Ba line.
5521·5	3	,,	Not present.	
5425·0	3	Not reversed.	,,	This line behaves in a very curious manner; it is so nearly of the same height as the one next less refrangible, that it sometimes appears longer and sometimes shorter as the spark flashes, and yet it is not given in Ångström's solar spectrum; it is given reversed in Kirchhoff's solar map, its number being 1371·3.
4933·4	4	Reversed.	Present.	Winged and very brilliant, reverses itself in the spark when the metal is used.
4899·3	4	,,	Not present.	Slightly shorter than the preceding one, and winged, but to a less extent.
4553·4	4	,,	Present.	Winged.
4524·4	4	,,	Not present.	Winged, and slightly shorter than the preceding line.
4165·5	3	Not reversed.	,,	Winged.
4130·5	3	,,	,,	,,

Thalén's lines were taken from the spectrum of Ba Cl_2; with a high tension spark the *metal* shows many more lines. The spectrum requires further investigation.

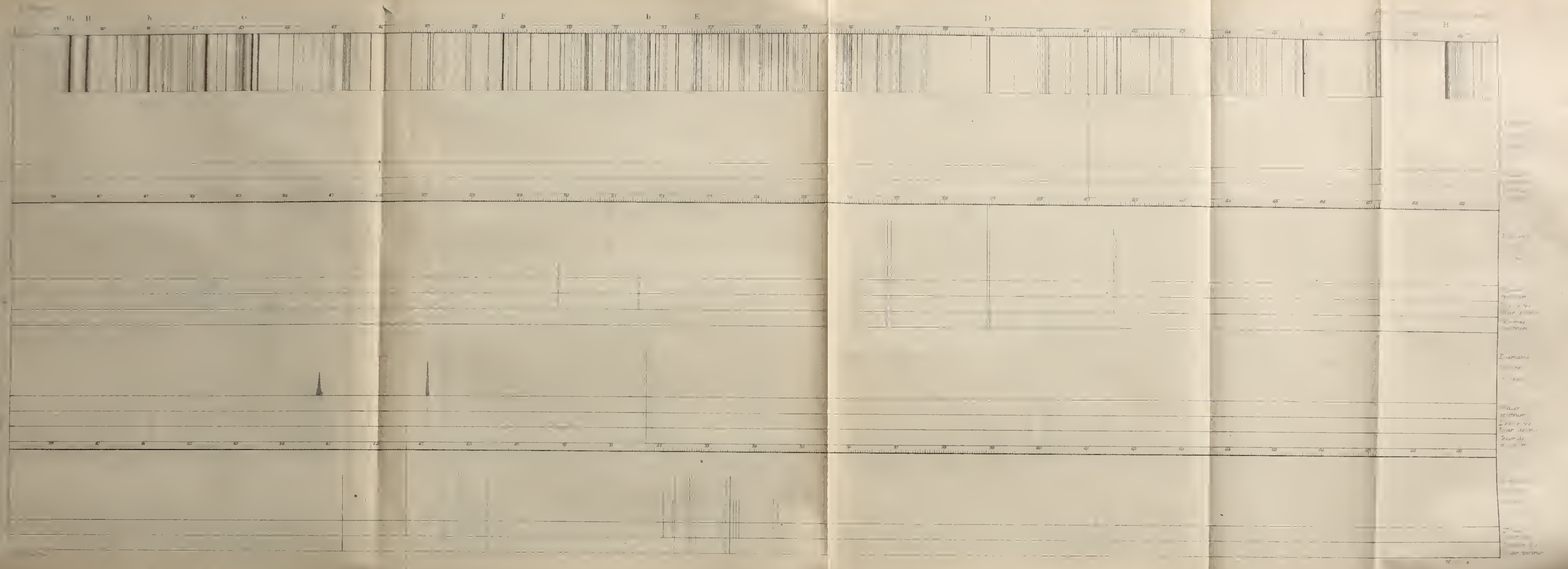


XIII

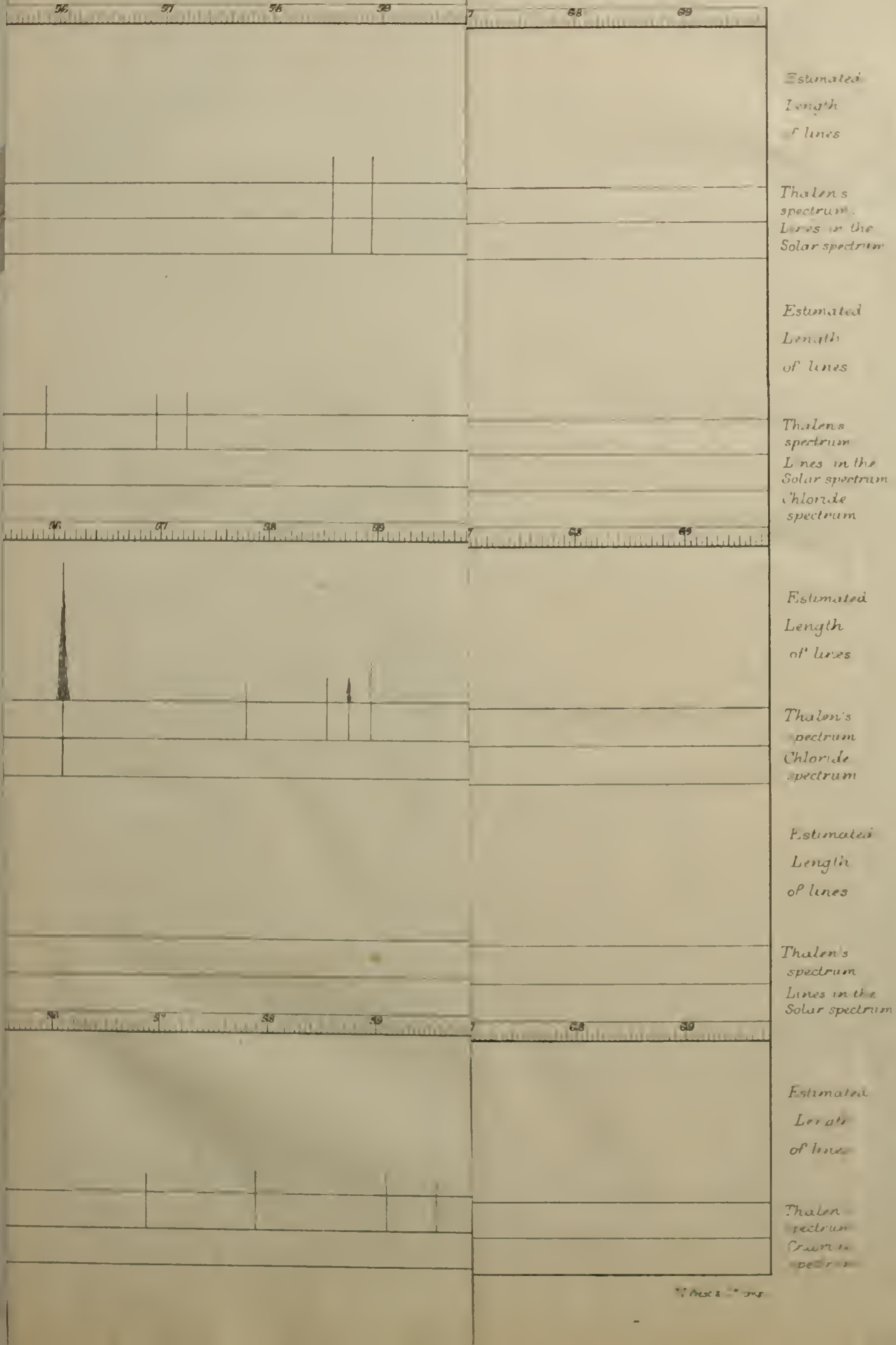

Estimated
Length
of lines
Thalen's
spectrum
Estimated
Length
of lines
Thalen's
spectrum
Lines in the
Solar spectrum
Chloride
spectrum
Estimated
Length
of lines
Thalen's
spectrum
Lines in the
Solar spectrum
Chloride
spectrum
Estimated
Length
of lines
Thalen's
spectrum
Sr
Estimated
Length
of lines
Thalen's
spectrum
Lines in the
Solar spectrum
Chloride
spectrum
Ba
?
66
67
68
69
W West & Co imp.

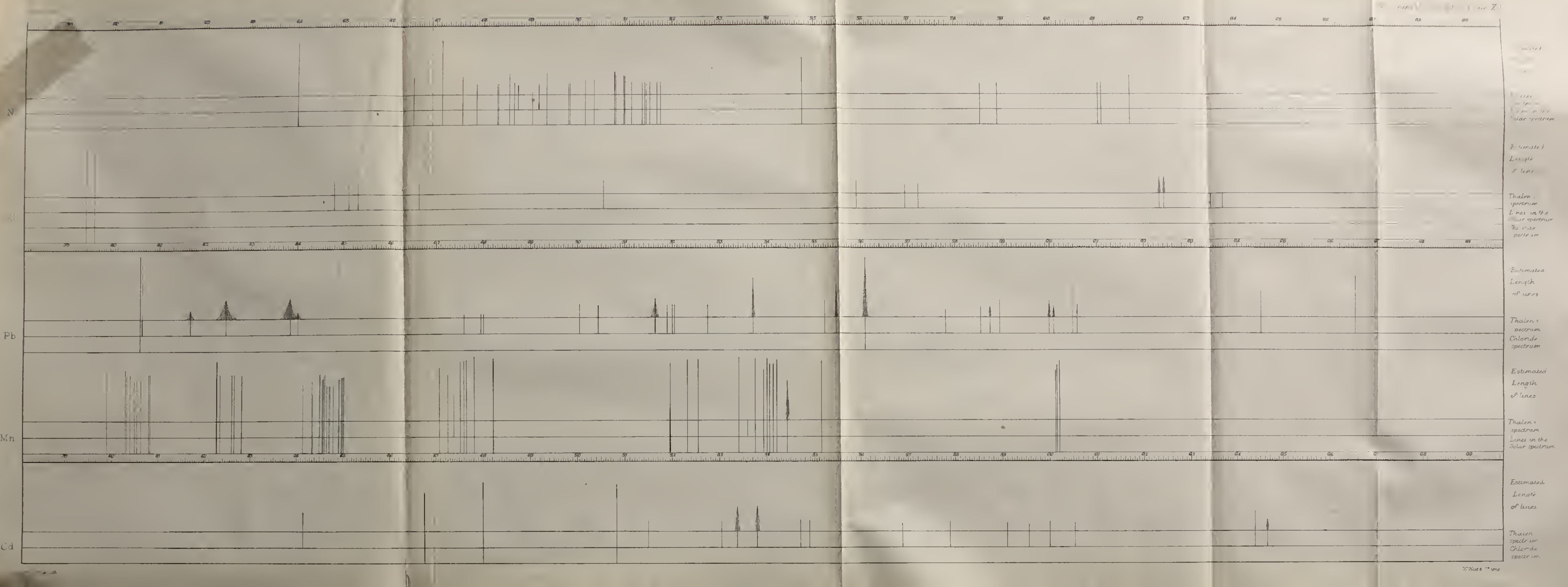


W West & Co sc et imp


H₁
H
h
G
F
b
E
D
B

Phil. Trans. MDCCCLXXIII Plate XII.


56
57
58
59
7
68
69
Estimated Length of lines
Thalen's spectrum
Lines in the Solar spectrum
Estimated Length of lines
Thalen's spectrum
Lines in the Solar spectrum
Chloride spectrum
56
57
58
59
7
68
69
Estimated Length of lines
Thalen's spectrum
Chloride spectrum
Estimated Length of lines
Thalen's spectrum
Lines in the Solar spectrum
56
57
58
59
7
68
69
Estimated Length of lines
Thalen's spectrum
Crown spectrum


N.
Pb
Mn
Cd
Estimated Length of lines
Thalen's spectrum
Lines in the Solar spectrum
Chloride spectrum

VI. *Researches on the Atomic Weight of Thallium.* *By* WILLIAM CROOKES, *F.R.S. &c.*

Received June 18,—Read June 20, 1872.

CONTENTS.

Page
INTRODUCTION 277

SECTION I.

ON THE DETERMINATION OF ATOMIC WEIGHTS .. 278

SECTION II.

APPARATUS EMPLOYED 280
The Balances 281
The air-balance 281
The vacuum-balance 281
Weighing in a vacuum 282
Correction for pressure and temperature 284
The Weights 287
Method of adjusting a set of weights 288
The Glass 294
Improved Sprengel vacuum-pump 295

SECTION III.

THE CHEMICALS 296
Water 296
Nitric acid 298
Oxalic acid 299
Sulphuric acid 300
Carbonic acid 301
Ammonia 301
Hydrogen 302
Thallium 302
Preparation of commercially pure thallium 303
- *a.* From the flue-dust of pyrites-burners .. 303
- *b.* From iron pyrites 306
- *c.* From sulphur or pyrites in the wet way .. 307
- *d.* From the saline residues of salt-works .. 307
- *e.* From commercial hydrochloric acid 307
- *f.* From the mother-liquors of the sulphate-of-zinc works at Goslar 307

Page
Preparation of chemically pure thallium 308
Purification of thallium by fusion in lime 309

SECTION IV.

PROCESSES AND RESULTS 310
Process of the conversion of thallium into nitrate of thallium 310
Obtaining a weighed quantity of thallium 310
Weighing the thallium and glass apparatus in a vacuum 313
Conversion of the thallium into nitrate of thallium 314
Weighing the nitrate of thallium and glass apparatus 316
Weighing the glass apparatus 316

SECTION V.

CALCULATION OF THE RESULTS 317
Density of atmospheric air 317
Values of $10+\log A_t$ 318
Influence of vapour of water 319
Values of $0{\cdot}378\times\frac{2}{3}v_t$ 319
First weighing in air of ordinary density 320
Second weighing in a rare atmosphere 320
Calculation of vacuum-weight of glass apparatus 321
Weighing of glass apparatus and nitrate of thallium 322
Ditto in a rare atmosphere 323
Calculation of vacuum-weight of glass apparatus and nitrate of thallium 323
First weighing in air of ordinary density 323
Second weighing in a rare atmosphere 324
Weight of thallium 325
Results 326
THE ATOMIC WEIGHT OF THALLIUM 329
Conclusion 330

IN June 1862, and in February 1863, I had the honour to lay before the Royal Society communications on the subject of the then newly discovered metal, Thallium. In these I gave an account of its occurrence, distribution, and the method of extraction from the ore, together with its physical characteristics and chemical properties; also

I discussed the position of thallium among elementary bodies, and gave a series of analytical notes.

In the pages of the 'Journal of the Chemical Society' for April 1, 1864, I collated all the information then extant, both from my own researches and from those of others, introducing qualitative descriptions of an extended series of the salts of the metal. I propose in the present paper to lay before the Royal Society the details and results of experiments which have engrossed much of my spare time during the last eight years, and which consist of very laborious researches on the atomic weight of thallium. In these researches I owe much to the munificence of the Royal Society for having placed at my disposal a large sum from the Government Grant. Without this supplement to my own resources it would have been difficult for me to have carried out the investigation with such completeness.

SECTION I.—ON THE DETERMINATION OF ATOMIC WEIGHTS.

In determining accurately the atomic weight of a metal that stands so high in the scale as thallium, difficulties and sources of error which are comparatively small with elements of low atomic weight are magnified to serious proportions, and require more than ordinary care for their elimination. When so large a proportion of the compound under analysis or synthesis consists of the body itself whose atomic weight is the one unknown quantity, it is evident that the almost unavoidable errors occasioned by impurity in the materials employed, the losses incident to imperfect manipulation, or the inaccuracies arising during the weighing from the omission of the corrections required by temperature, pressure, &c., will all find their way into the number which is finally considered to represent the atomic weight of the metal.

Nearly fourteen years ago, on taking the chair of the Chemical Section of the British Association at Leeds, the late Sir JOHN HERSCHEL called attention to the necessity which there then was for the introduction of greater accuracy into the determination of atomic weights. Speaking of the numerical relations which appear to exist between certain groups of elements, he considered that all these speculations took for granted a principle with which chemists had allowed themselves to be far too easily satisfied, viz. that all the atomic numbers are multiples of that of hydrogen. "Not until these numbers," he continues, "are determined with a precision approaching that of the elements of the planetary orbits—a precision which can leave no possible question of a tenth or a hundredth of a per cent., and in the presence of which such errors as are at present regarded tolerable in the atomic numbers of even the best determined elements shall be considered utterly inadmissible—I think can this question be settled; and when such gigantic consequences—so entire a system of nature—are to be based on a principle, nothing short of such evidence ought, I think, to be held conclusive, however seductive the theory may appear. I do not think such precision unattainable; and I think I perceive a way in which it might be attained, but one that would involve an expenditure of time, labour, and money, such as no private individual could bestow on it." Before this remarkable sentence was written Professor Stas had commenced his classical researches on the atomic weights; and in 1861 he gave to the world the results of ten years' experiments, which had been conducted with a care and perseverance never surpassed in the history of experimental investigation. These researches of Professor Stas, and others which he has since made public, constitute a standard of excellence which chemists who are engaged on the important task of the determination of atomic weights should strive to attain. They are, in my opinion, the most noteworthy chemical memoirs that have ever been written: not only have they determined in the most definite and unassailable manner atomic weights about which scarcely any two chemists have agreed since the time of Berzelius, but they have raised the standard of accuracy in all chemical laboratories, and have set an example which, if followed, cannot fail to exert an important influence on the progress of chemical science.

It has been with these researches before me that I have endeavoured to determine in a manner which should approach them in accuracy the atomic weight of thallium.

In the determination of an atomic weight analysis is inferior to synthesis; and especially is this the case when the number sought is amongst the highest known. The method followed should be one in which as few chemical elements as possible are employed, so as to reduce to a minimum the errors arising from inaccuracy in the determination of their atomic weights,—which errors, whilst they might on the one hand balance each other, on the other might accumulate in the same direction, and become a total error of exceeding magnitude in the atomic weight of the metal under investigation. The method adopted should also be one in which there is the greatest possible difference of weight between the substance taken for the starting-point and the one ultimately obtained; for the greater the amount of this difference, other things being equal, the less likely are the unavoidable errors incidental to the method, and which may be looked upon as constant, to injuriously affect the atomic weight obtained. For these reasons processes in which a weighed quantity of the metal itself is taken and converted into one of its salts seemed likely to afford the best results; and this accordingly is the principal method which I have adopted.

Every substance employed in such a determination is liable to introduce errors proportionate to its own want of purity. The most extraordinary pains have therefore been taken to secure the absolute purity both of the thallium employed and of the agents used to act upon it. The glass and other apparatus have been specially constructed for these researches, and the balances and weights have been of an accuracy never before surpassed in any research. Whilst nearly every other branch of manipulative chemistry has advanced to an accuracy vieing with astronomical observation, the operation of weighing, as almost universally carried out, is attended with grave imperfections. For ordinary analytical work, and perhaps even for more refined and accurate researches, the errors attending the ordinary process of weighing are unimportant; but in determining an equivalent so high as that of thallium no precaution whatever which can either reduce an error to a minimum or eliminate it altogether should be neglected. I am anxious to avoid the imputation of over-refinement in this research; but considering the fallibility of human operations, and especially those of so complicated a nature as I am about to describe, I have considered it better to err on the side of too great than of too little precaution, both in the purification of the chemicals, the arrangement of the apparatus, the time devoted to each separate determination, the removal of the errors incidental to the weighings, and the subsequent calculations. These latter have been especially tedious, as the numbers have generally extended to too many places of figures to allow the use of logarithms; each calculation has, moreover, been duplicated by different persons.

I have attempted two entirely different methods of arriving at the atomic weight of thallium. Had the results of these determinations differed materially, I should have extended the research to other methods; but as they nearly agree it appeared unnecessary to incur so great an additional expenditure of time and material with no reasonable prospect of getting any but confirmatory results.

The first method, and that which I shall describe, consists in taking a known quantity of metallic thallium, dissolving it in nitric acid, and weighing the nitrate of thallium produced.

The second method consists in dissolving known quantities of sulphate of thallium in water, and ascertaining how much nitrate of barium is necessary to precipitate the sulphuric acid as sulphate of barium.

In the prosecution of these two methods, the materials employed, the transferences from one vessel to another, and the weighings are reduced to a minimum, while several precautions have been introduced into the operations of weighing which are not usually adopted. No correction has been neglected that is not many times less than the probable error of a single observation; and, as I have stated, especially has attention been paid to such corrections as always influence in one direction, as in that for weight of air displaced. Errors sometimes in excess and sometimes in defect tend to disappear from the mean of a great number of observations.

I have for the foregoing reasons thought it necessary to dwell thus far upon the care I have bestowed upon my work. In the succeeding section I shall describe accurately the apparatus employed, including the balance and weights, and the necessary arrangements for weighing *in vacuo*. In the third section I shall enumerate the chemicals and the methods of preparing them and pure thallium. The fourth section will be devoted to the process determining the atomic weight and the weights obtained. The concluding section will consist of a calculation and discussion of results.

SECTION II.—APPARATUS EMPLOYED.

The absolute weight of any substance may be found by calculation from its apparent weight in an atmosphere balancing 30 inches of mercury, and from its apparent weight under, say, 25 inches of mercury; but the errors of observation, more especially those relating to the maintaining of a partial vacuum, will largely affect the result. Weighings obtained in atmospheres balancing 30 inches of mercury and 5 inches of mercury respectively will give a more accurate result; but the best weighings whereby the absolute weight of a substance may be calculated are undoubtedly one in air at ordinary pressure and temperature, and one in a highly rarefied atmosphere,—it cannot be said *in vacuo*, owing to the difficulty of working under such a difference of pressure between the atmosphere of the balance and that surrounding it.

The Balances.

Two balances were used. That which I shall call the *air*-balance was made by Messrs. KEISSLER and NEU expressly for this work, and will clearly indicate a difference of 0·0001 of a grain when loaded with 1000 grains in each pan*. It is always kept in a dry room of tolerably uniform temperature, away from draught, artificial heat, or chemical vapours, and was (in the most accurate experiments) only used when no fire had been in the room for at least twelve hours.

The second balance, which I shall call the *vacuum*-balance, is almost a duplicate of the first, of 14-inch beam, with agate knife-edges and planes, made by OERTLING. It is enclosed in a cast-iron case connected with an air-pump, and so arranged that I can readily weigh any substance in air of any desired density, the rarefaction being measured by a barometer-gauge. The accompanying diagram (Plate XIV.) shows the method of the connexions. The upper and lower portions of the iron case are connected by flanges and bolts; while to ensure that the joint shall be air-tight, there is cemented to each flange a band of thick unvulcanized india-rubber, a lead wire being laid between the two pieces of india-rubber. By this means, and by causing the arm by which the riders are adjusted and the key liberating the pans and beam to work in a double-packed stuffing-box, a nearly perfect vacuum can be maintained. The openings in the metal work, through which observations are made, are fitted with clear stout plate glass; that to the left of the centre of the case, for the introduction of the apparatus &c., is closed with an iron door, clamped and fitted with washers. The apparatus, when attached to the air-pump and exhausted to 25 inches of mercury, seldom allows the column of mercury to sink at a greater rate than 0·01 inch in an hour. A plug of gold-leaf is inserted in the tube connecting the barometer-gauge with the vacuum-chamber, in order to absorb any mercury vapour that might otherwise be carried over.

---

* M. STAS employed four balances. One of them when loaded with 1000 grammes turns with $\frac{5}{10}$ of a milligramme; another when loaded with 5000 or 6000 grammes turns with 1 milligramme, and with 2000 or 3000 grammes in each pan turns with $\frac{3}{10}$ or $\frac{4}{10}$ of a milligramme. The third balance loaded with 500 grammes turns with $\frac{2}{10}$ of a milligramme; the fourth laden 25 grammes turns to $\frac{1}{33}$ of a milligramme. Reducing these weights to grains, we find that—

No. 1	loaded with	15,432 grains	turns with	0·0077	grain.
„ 2	„	92,592	„	0·0154	„
„ 2	„	46,296	„	0·0060	„
„ 3	„	7,716	„	0·0030	„
„ 4	„	386	„	0·0005	„

Even with moderate rarefaction the iron case of the balance showed at first a certain amount of porosity, due to the "kish" or graphite, carbide, and silicide diffused through the metal like a sponge. Cast-brass and even drawn-brass tubes exhibit a similar porosity. This porosity in the casing of the balance admits of easy remedy, by painting the whole surface with two or three thin coats of white-lead paint mixed with boiled linseed-oil or fine copal-oil varnish, allowing each coat to dry before the next is laid on. The vessel should be painted when it is partially exhausted; the multitude of small holes then appearing in the smooth surface of the paint as it is forced inwards by the pressure of the outer air should be covered carefully with thin coats of paint. When this effect ceases, a final thin coat should be given and allowed to dry.

The iron flanges were first planed true with the planing-machine, and then "fined off" by WHITWORTH'S process of scraping, generally employed for such work as slides of engines &c. The lead wire laid between the flanges of the iron case in india-rubber, becoming compressed when the bolts are tightened, effectually precludes the entrance of air. The washers of the iron door to the left of the case are of well-greased leather, while the glass plates in the other parts of the apparatus are cemented into double frames with red lead.

At first it was attempted to put nearly the correct weight into the pan, and then make the final adjustment by means of the rider. It was, however, soon found that the more accurate method was to introduce a certain weight, and then to alter the pressure of the air until the balance shows equilibrium. Thus, supposing a glass vessel weighing in air 625·1200 grains has to be weighed *in vacuo*, calculation estimates the probable weight (*in vacuo*) at 625·3700. I therefore introduce rather less (625·3600) than this weight, and exhaust until the balance attains equilibrium, when the gauge shows an atmospheric pressure equal (say) to 3·75 inches of mercury. When this is obtained the weight is slightly increased or diminished with the rider, and the exhaustion varied until a fresh equilibrium is established. Two weighings at different degrees of atmospheric pressure, varying by a considerable interval, give data upon which to calculate with great accuracy what the weight would be in a perfect vacuum.

With a rider there is some difficulty in estimating the exact point at which it rests, and it is necessary to note the oscillations, placing the rider as exactly as possible on one of the divisions of the beam. The best weighings, perhaps, will be taken when the arc is not very small.

Temperature has an effect upon the air-balance, rendering it less sensitive when increasing. This is perhaps due to the varying expansibility of the arms and the knife-edges upon which the pans are hung, or the superior and inferior parts of the beam may expand unequally. The two arms of the balance at times expand unequally; and in finding the true value of the weights employed in the determination, this cause of error is eliminated by following GAUSS'S method of interchanges—the constant friction of the forceps against the weights in transferring them from one pan to another being obviated by employing hooks of thin wire attached to the agate plane, upon which the suspension-wires of the pans could be hung. This required that the pans should not differ from each other by a quantity greater than one thousandth of a grain.

In heavy weighings it is found convenient to remove one of the pans; but as the case is one of determining a weight and its increase after certain operations, the removal of the pan does not affect the result, provided the weight of the pan is accurately ascertained and this weight allowed for, the apparatus weighed appearing lighter to an amount equal to this weight. Always when weighing different metals, or glass, or some chemical against metal, it is necessary to correct for the weight of air displaced, reference being at the same time made to the temperature and air-pressure; for assuming that there are to be weighed 7000 grains of bronze against 7000 grains of platinum, there will arise an error of nearly 0·6 of a grain unless this precaution be attended to, for 7000 grains of bronze displace roughly 1 grain of air, while 7000 grains of platinum displace only 0·4 grain.

At each weighing at diminished air-pressure care must be taken to allow the balance to remain at rest for at least half an hour, and preferably for several hours, in order to allow the temperature to become uniform after the alteration caused by the exhaustion. The weighings were always repeated a second time after every thing had been allowed to remain at rest for one hour; and when the final weighing was made, the case had been unopened for six hours, the adjustment being made by slightly altering the density of the enclosed air.

One of the greatest difficulties occurred in endeavouring to illuminate the scale and pointer of the balance without heating sufficiently to introduce a cause of error. The concentrated rays of a lamp were found to be unsuited in several ways. The use of a small vacuum-tube suspended inside the iron case was finally decided upon, sufficient light being obtained with two Grove's cells actuating a small induction-coil placed some distance from the apparatus, the electricity being conveyed by fine conducting-wires of good copper, carefully insulated*. These wires pass into the case through grooves filed in the flanges and well protected with india-rubber bands, and in no way interfere with the obtaining of a vacuum.

To prevent parallax the scale and pointer are viewed through a small telescope having a vertical wire in the focus of the eyepiece. The observer is therefore able to be situated some eight or ten feet from the balance during accurate observations, thus reducing to a minimum the disturbance due to the temperature of the body. It is inexpedient to estimate the value of a division on the ivory scale over which the pointer of the balance travels, as its value varies with the length of arc of vibration, with the weight in the pans, and slightly with the temperature. It is also evident that GAUSS's method of weighing in alternate pans is inapplicable when weighing in a rare atmosphere, owing to the number of times the case would have to be opened, and the consequent liability to other sources of error. BORDA's method, as described by PÉCLET in his

---

[*] At high rarefactions this method of illumination fails, owing to the induced current passing between the wires outside the vacuum-tube.]

'Cours de Physique,' gives the most accurate results with the least expenditure of time. The weights are placed in the left-hand pan, and the object to be weighed in the right. At the last three consecutive oscillations of the pointer along the divided scale the division reached by the pointer is recorded, and

$$\frac{a+c+2b}{4}=$$

the reading of the scale when the balance attains equilibrium. It is better to allow the first oscillation to occur unnoticed, and to record only the next three consecutive oscillations, while the first can be employed to check the result if required.

Finally, the balance-case contains a jar of pure oil of vitriol exposing a large surface, and another of caustic potash. The air is admitted through long U-shaped tubes, one filled with chloride of calcium, and the other with platinized asbestos.

For each weighing all necessary observations of the barometer and thermometer were made, as will be found noted in the fourth and fifth sections of this memoir.

I would here ask whether chemists in their analytic analyses sufficiently allow for barometric variation. The temperature at the time of weighing is generally recorded: chemists have known the influence of pressure on the boiling-point, and its effect upon gases, yet they appear to neglect reference to the barometer when weighing solids, forgetting that they are weighing in a gas which itself possesses weight. Weighings are repeated after some operation, such as expelling moisture, at intervals sufficiently long to admit of considerable variation in atmospheric pressure, and the increase or decrease of a few milligrammes in weight is considered to determine the gain or loss of certain constituents. It remains to be seen whether a neglect of variation in barometric pressure would not account for these minute differences.

An approximation to the true weight of bodies, that is their weight *in vacuo*, may be obtained by the following formula, when their specific gravity and weight in air of 760 millims. pressure of mercury at 0° C. is known.

Let W = weight in grains; then the weight of air displaced is

$$\frac{\mathrm{W}}{\text{sp. gr.}}\times 0\cdot 00122.$$

This weight plus the value of the weights *in vacuo* balancing the substance is its true weight *in vacuo*.

Let the weight of 800 grains of water in 200 grains of glass be required from two assistants, the one weighing against brass, the other against platinum weights, neglecting (1) the weight of air displaced and (2) its variation in weight from barometric disturbances.

(1) The true value of 800 grains of water weighed in air (bar 760 millims., 0° C.) =800·976 grains.

That of 200 grains of glass . . =200·0976 grains.
Weight of air displaced by water =0·976 grain.
" " glass =0·0976 "

A brass weight of 1000 grains in use in my laboratory displaces 0·1462 grain of air; a 1000-grains platinum weight, 0·058271 grain of air.

The weight of glass and water . . . =1000·0000 grains.
" air displaced by them . = 1·9736 "
Weight of glass and water . . . . 1001·9736

Glass and water . . . . =1001·9736 grains.
Less air displaced by weight (brass) . = 0·1462 "
1001·8274 grains = the true value of the water and apparatus received from the assistant employing brass weights.

Glass and water . . . . =1001·973600 grains.
Less air displaced by weight (platinum) . = 0·058271 "
1001·915329 grains = the true value of the water and glass received from the assistant employing platinum weights.

(2) In a note to the translation of DESCHANEL'S 'Natural Philosophy'* by Professor EVERETT, it is said, "In strictness the weight in grammes of a litre of air under the pressure of 760 millimetres of mercury is different in different localities, being proportional to the intensity of gravity—not because the force of gravity in the litre of air is different (for though this is true, it does not affect the numerical value of the weight when stated in grammes), but because the pressure of 760 millimetres of mercury varies as the intensity of gravity. So that more air is compressed into the space of a litre as gravity increases. The *weight in grammes* is another name for the *mass*. The force of gravity on a litre of air under the pressure of 760 millims. is proportional to the square of the intensity of gravity. This is an excellent example of the ambiguity of the word *weight*, which sometimes denotes a mass, sometimes a force; and though the distinction is of no practical importance so long as we confine our attention to one locality, it cannot be neglected when different localities are compared." In one locality we have to deal with differences of air-pressure alone. Assumed that we are weighing at Greenwich, where gravity is to that of Paris as 3457 to 3456, the weight of a litre of dry air at Paris being 1·293167 grm. at 0° C. at a barometric height of 760 millims., the weight of a litre of air at Greenwich at the same barometric and thermometric heights will be 1·293561 grm. Knowing the weight of a litre of air at 760 millims. barometric height, at a lower height of the mercurial column the weight will be proportionately less, the temperature beings upposed constant; so that the weight of air displaced with the barometer at 740 millims. by the glass apparatus and water will be 1·9216 grain, and at 715 millims. 1·8890 grain. The brass weight will displace 0·1424

---

* Part I. p. 141.

grain of air at 740 millims. and 0·1385 grain at 715 millims.; the platinum weight will displace 0·56737 grain of air at 740 millims., and 0·054666 grain at 715 millims. The assistant weighing with brass weights would give then

Under 760 millims. an error of 1·8276 grain
„ 740 „ „ 1·7792 „ } on the 1000.
„ 715 „ „ 1·7505 „

The assistant weighing with platinum weights would give

Under 760 millims. an error of 1·915329 grain
„ 740 „ „ 1·864863 „ } on the 1000.
„ 715 „ „ 1·834334 „

Proceed on another supposition. Let the apparatus be weighed on two days, the barometer readings being respectively 740 millims. and 715 millims. Weighed on, say, the first day at 715 millims., on the second day there would be an apparent increase of nearly 0·029 grain; and if weighed again on a third day at 760 millims. an increase of 0·0771 grain, or against platinum weights nearly 0·081 grain.

Had a specifically lighter fluid than water been taken, or exceptional cases exemplified, it would have been possible to have largely increased these numbers; but they are a fair average of the errors unrecognized in ordinary manipulation.

To select another instance. In the determination of the amount of carbonic acid yielded by an organic body under combustion, the weight of the potash and bulbs is always sufficiently great to introduce an error arising from neglect of barometric variation. Thus, taking the potash and bulbs to weigh 600 grains, there would be displaced 0·336 grain of air at 760 millims. pressure, 0·327 grain at 740 millims., and 0·316 grain at 715 millims. Between 715 and 760 millims. there is an increase of weight of 0·02 gr., or, supposing 3·5 grs. of the substance under analysis had been taken, an increase of nearly 0·6 per cent. Again, a chloride-of-calcium tube, weighing, with its contents, 350 grs., displaces 0·2135 gr. of air at 760 millims. pressure. Between 715 and 760 millims. there will be an increase of 0·0127 gr., or of 0·36 per cent. Thus, in the estimation of the carbonic acid and of the water yielded by the organic body, the total error introduced by barometric variation is nearly 1 per cent. I need not quote illustrations of the effect of such an error upon the formula deduced; it will perhaps account for the difference from theory often obtained in the results of carefully conducted analyses.

The preceding calculations show that a simple formula may be stated which shall include the corrections on a certain volume of air for pressure and for temperature. It is

$$W=1{\cdot}293651 \text{ grm. } V\frac{1}{1+0{\cdot}00367\,T}\cdot\frac{P}{760},$$

where W is the weight in grammes of a volume (V) of air at a pressure P and temperature T, 0·00367 being the coefficient of the expansion of air. For accurate experiments, it will be necessary to substitute the weight of a litre of air in the locality of the laboratory for the coefficient of V. The formula, as it now stands, is calculated for the volume in litres; if a cubic centimetre be taken, the coefficient of V becomes 0·001293651; if a cubic decimetre, 0·01293651. For laboratory purposes, the ratio of the pressures might be tabulated; this is scarcely necessary, however, if the ratio 759 : 760 be taken = 0·9987 as sufficiently accurate, for a tabular difference of 0·0013 will enable the operator to speedily determine the ratio he requires.

In particularly describing the vacuum-balance, I have one peculiarity to note in relation to the effect of heat in diminishing the weight of bodies. That a hot body should appear to be lighter than a cold one has been considered as arising from the film of air or aqueous vapour condensed upon or adhering to the surface of the colder body, or from the upward currents of air caused by the expansion of the atmosphere in the vicinity of the heated body. But neither hypothesis can be held when the variation of the force of gravitation occurs in a vacuum as perfect as the mercurial gauge will register, and under other conditions which I am now supplying, and which I purpose embodying in a paper to be submitted to the Royal Society during a subsequent session.

The Weights.

A set of weights as ordinarily supplied by even the best instrument-makers is never absolutely exact; however carefully they may be adjusted, the pieces of metal which respectively represent 1000 grs., 100 grs., 10 grs., &c. are only more or less approximations to the true weights. In most chemical analyses, the error arising from such inaccuracies in the weights used is so small, in comparison to errors of manipulation or to imperfections inherent in the chemical processes adopted, that it may generally be disregarded; but when the chemist has for his object the determination of an atomic weight, or is engaged in other researches demanding the highest refinement of accuracy which chemistry and physics can supply, then he is bound to neglect no correction which will increase the precision of the results. That chemists, whose well-trained reasoning powers allow them to take for granted nothing which is not capable of experimental verification, and who insist upon the utmost attainable precision in their balances, should, as a rule, neglect the probable errors which the inaccuracies of their weights may introduce, is somewhat inconsistent. But in considering these eliminations in my memoir, I must disclaim any originality in the process, the description of the method I employed being intended solely to place others on the same footing as myself in their judgment of the possible inaccuracies of my investigations and their effect on the result.

Professor W. H. MILLER, of Cambridge, in his valuable researches on the determination of the standard pound (Philosophical Transactions for 1856, pp. 811, 827, 937), has given full directions for attaining a similar object. These, however, will not exactly apply to the systems of weights used by chemists; for, of the three cases described by him, the former two concern a peculiar system of weights, and in the third, two sets of weights (one for the Exchequer, the other for the Royal Mint) were compared at the same time. To this paper, as well as to the learned author himself, I am indebted for a valuable store of information on the subject of weights and weighings.

The weights employed were of platinum, made expressly for these investigations by Messrs. Johnson and Matthey. The platinum was quite pure; it was fused, cast, and then well hammered. The weights were adjusted by myself during May, June, July, and August 1864: they were first roughly adjusted, and then the specific gravity of each weight was taken. The weights were heated to redness in a bath of magnesia previous to ascertaining their specific gravity. The density of the larger weights was ascertained to the second place of decimals, and that of the smaller ones to the first place. The record of the final adjustment of these weights will be sufficient to show the method I adopted.

In taking the specific gravity of the weights, the distilled water was contained in a glass beaker of about 250 cubic inches capacity. Each weight was suspended by a fine platinum wire to be attached to the pan of the balance. With this wire affixed the weight was introduced into a small glass vessel filled with water, and heated over a spirit-lamp to the boiling-point. When all the air-bubbles had been expelled by this process, the small jar containing the weight was lowered into the water in the beaker, the weight, on removing the small jar, being perfectly free from any adhering bubbles of air. After the temperature had sunk to the proper point, the specific gravity was taken.

The 1000-grain weight was selected as the standard; for in nearly every process in which weights are used in chemistry, the object is not to ascertain the *absolute* weight of a substance in terms of a grain or gramme, but to determine its *relative* weight in comparison with that which it possessed at some other time before it was submitted to certain analytical or synthetical operations. If the weighings are performed with the same weights, it does not at all matter whether the weights are absolutely of the value which they profess to be; but it is very important that they should bear a known proportion to each other. This must be understood as referring only to ordinary chemical research in synthesis or analysis. In many physical investigations it is of great importance that the 1000-grain weight should really represent 1000 normal grains, or that its deviation from that value should be accurately determined; but I confess I do not know where a standard weight suitable for such a comparison is to be met with. The weights at first tried were far from accurate among themselves. I accordingly ascertained their errors by the method described below, and then adjusted them myself according to the corrections thus found necessary. The residual errors in the weights were then finally taken in the following manner:—

The balance being brought into equilibrium and the temperature and barometrical pressure carefully noted, the 1000-grain weight was placed in the left pan, and in the right the 600, the 300, and the 100-grain weights. It was now found that, to bring the balance back to equilibrium, a slight additional weight had to be placed on the right side to supplement the three weights already in that pan. This was noted. The weights were then removed to the opposite sides, the 1000 grains being on the right and the three smaller weights on the left. It was now found that a small weight had to be subtracted from the side carrying the three weights in order to produce equilibrium. The weights were removed and interchanged in this manner ten times, so as to eliminate, as far as possible, the errors arising from observation, or the unequal expansion by heat of the arms of the balance; and by applying the method of least squares to the results obtained, the following equation was arrived at:—

$$(1000)=(600)+(300)+(100) \quad + \; 0{\cdot}01000 \quad . \;\; . \;\; . \quad a,$$

the figures within parentheses representing the nominal value of the actual pieces of platinum stamped 1000, 600, 100 grains, &c.

In a similar manner the values of the remaining weights were ascertained; thus,—

$$\begin{array}{lll}
(600)=(300)+(200)+(100) & +\;0{\cdot}00777 & .\;.\;.\;\; b. \\
(300)=(200)+(100) & +\;0{\cdot}00991 & .\;.\;.\;\; c. \\
(200)=(100)+(60)+(30)+(10) & +\;0{\cdot}01577 & .\;.\;.\;\; d. \\
(100)=(60)+(30)+(10) & -\;0{\cdot}00030 & .\;.\;.\;\; e. \\
(60)=(30)+(20)+(10) & -\;0{\cdot}00522 & .\;.\;.\;\; f. \\
(30)=(20)+(10) & +\;0{\cdot}00154 & .\;.\;.\;\; g. \\
(20)=(10)+(6)+(3)+(1) & +\;0{\cdot}00355 & .\;.\;.\;\; h. \\
(10)=(6)+(3)+(1) & +\;0{\cdot}00052 & .\;.\;.\;\; i. \\
(6)=(3)+(2)+(1) & -\;0{\cdot}00102 & .\;.\;.\;\; j. \\
(3)=(2)+(1) & +\;0{\cdot}00165 & .\;.\;.\;\; k. \\
(2)=(1)+({\cdot}6)+({\cdot}3)+({\cdot}1) & -\;0{\cdot}00312 & .\;.\;.\;\; l. \\
(1)=({\cdot}6)+({\cdot}3)+({\cdot}1) & -\;0{\cdot}00508 & .\;.\;.\;\; m. \\
({\cdot}6)=({\cdot}3)+({\cdot}2)+({\cdot}1) & -\;0{\cdot}00260 & .\;.\;.\;\; n. \\
({\cdot}3)=({\cdot}2)+({\cdot}1) & +\;0{\cdot}00225 & .\;.\;.\;\; o. \\
({\cdot}2)=({\cdot}1)+({\cdot}06)+({\cdot}03)+({\cdot}01) & -\;0{\cdot}00100 & .\;.\;.\;\; p. \\
({\cdot}1)=({\cdot}06)+({\cdot}03)+({\cdot}01) & -\;0{\cdot}00802 & .\;.\;.\;\; q. \\
({\cdot}06)=({\cdot}03)+({\cdot}02)+({\cdot}01) & -\;0{\cdot}00607 & .\;.\;.\;\; r. \\
({\cdot}03)=({\cdot}02)+({\cdot}01) & -\;0{\cdot}00642 & .\;.\;.\;\; s. \\
({\cdot}02)=({\cdot}01)+({\cdot}01r'')^{*} & -\;0{\cdot}00118r' & .\;.\;.\;\; t. \\
({\cdot}01)=({\cdot}01r'') & +\;0{\cdot}00413r' & .\;.\;.\;\; u. \\
({\cdot}01)=({\cdot}01r') & +\;0{\cdot}00410r'' & .\;.\;.\;\; v.
\end{array}$$

---

* r', r'' represent riders, two of which were adjusted in this manner.

We have now the data for ascertaining the absolute values of the weights in terms of the (1000) weight taken as standard. Adding the equations a and b gives

$$(1000)=2(300)+(200)+2(100)+0\cdot01777.$$

Multiplying equation c by 2 gives

$$2(300)=2(200)+2(100)+0\cdot01982.$$

Subtracting e from d gives

$$(200)=2(100)+0\cdot01607.$$

Now by $(a+b)+2c+3(d-e)$ we get

$$(1000)=10(100)+0\cdot01777+0\cdot01982+0\cdot04827;$$

$$\therefore (1000)=10(100)+0\cdot08580;$$

$$\therefore \frac{(1000)}{10}= (100)+0\cdot008580;$$

$$\therefore (100)= 100-0\cdot008580;$$

$\therefore (100)=99\cdot991420$ grains. . . . . . . A.[*]

Substituting this value for the (100) weight, we get from equation e,

$$99\cdot991420=(60)+(30)+(10)-0\cdot00030;$$

$\therefore (60)+(30)+(10)=99\cdot991720$. . . . . B.

From equation d we therefore get

$$(200)=99\cdot991420+99\cdot991720+0\cdot01577;$$

$\therefore (200)=199\cdot998910$. . . . . C.

From equation c we get

$$(300)=199\cdot998910+99\cdot991420+0\cdot00991;$$

$\therefore (300)=300\cdot000240$. . . . . D.

From equation b we get

$$(600)=300\cdot000240+199\cdot998910+99\cdot991420+0\cdot00777;$$

$\therefore (600)=599\cdot998340$. . . . . E.

Again, adding e and f,

$$(100)=2(30)+(20)+2(10)-0\cdot00552;$$

$\therefore$ from A,

$$99\cdot991420=2(30)+(20)+2(10)-0\cdot00552.$$

Multiplying g by 2,

$$2(30)=2(20)+2(10)+0\cdot00308.$$

---

[*] Although these decimals are carried to the sixth place, the balance would not indicate beyond the fourth place. By taking the mean of ten interchanged weighings, I could obtain a fifth place. The calculated values of the weights were carried to a sixth decimal, in order to avoid inaccuracy in the fourth and fifth places when several values were summed.

Subtracting i from h,

$$(20)=2(10)+0{\cdot}00303.$$

By adding e, f, twice g, and thrice the last equation, we get

$$99{\cdot}991420=10(10)+0{\cdot}000665;$$

$\therefore (10)=9{\cdot}998477$. . . . . F.

From equation i we get

$$9{\cdot}998477=(6)+(3)+(1)+0{\cdot}00052;$$

$\therefore (6)+(3)+(1)=9{\cdot}997957$. . . . . . G.

Substituting these values in h we get

$$(20)=9{\cdot}998477+9{\cdot}997957+0{\cdot}00355;$$

$\therefore (20)=19{\cdot}999984$. . . . . H.

From g we get

$$(30)=19{\cdot}999984+9{\cdot}998477+0{\cdot}00154;$$

$\therefore (30)=29{\cdot}999991$. . . . . I.

From f we get

$$(60)=29{\cdot}999991+19{\cdot}999984+9{\cdot}998477-0{\cdot}00522;$$

$\therefore (60)=59{\cdot}993232$. . . . . J.

Again, adding i and j,

$$(10)=2(3)+(2)+2(1)-0{\cdot}00050.$$

Multiplying k by 2,

$$2(3)=2(2)+2(1)+0{\cdot}00330.$$

Subtracting m from l,

$$(2)=2(1)+0{\cdot}00196.$$

Then $(i+j)+2k+3(l-m)$ gives

$$(10)=10(1)+0{\cdot}00868;$$

$$\therefore 9{\cdot}998477=(10)1+0{\cdot}00868;$$

$$\therefore 0{\cdot}9998477=(1)+0{\cdot}000868;$$

$\therefore (1)=0{\cdot}9989797$. . . . . K.

From equation m we have

$$0{\cdot}9989797=({\cdot}6)+({\cdot}3)+({\cdot}1)-0{\cdot}00508;$$

$\therefore ({\cdot}6)+({\cdot}3)+({\cdot}1)=1{\cdot}0040597$. . . . . L.

From l,

$$(2)=0{\cdot}9989797+1{\cdot}0040597-0{\cdot}00312;$$

$\therefore (2)=1{\cdot}9998394$. . . . . M.

From k,

$(3)=1\cdot9998394+0\cdot9989797+0\cdot00165$;

$\therefore (3)=3\cdot0004691$. . . . . N.

From j,

$(6)=3\cdot0004691+1\cdot9998394+0\cdot9989797-0\cdot00102$;

$\therefore (6)=5\cdot9982682$. . . . . O.

Again, adding m and n,

$(1)=2(\cdot3)+(\cdot2)+2(\cdot1)-0\cdot00768$.

Multiplying o by 2 we get

$2(\cdot3)=2(\cdot2)+2(\cdot1)+0\cdot00450$.

Subtracting q from p,

$(\cdot2)=2(\cdot1)+0\cdot00702$.

Then $(m+n)+2o+3(p-q)$ gives

$(1)=10\ (\cdot1)+0\cdot01788$;

$\therefore 0\cdot9989797\ =10(\cdot1)+0\cdot01788$;

$\therefore 0\cdot09989797=\ (\cdot1)+0\cdot001788$;

$\therefore (\cdot1)=0\cdot09810997$. . . . . P.

From q we get

$0\cdot09810997=(\cdot06)+(\cdot03)+(\cdot01)-0\cdot00802$;

$\therefore (\cdot06)+(\cdot03)+(\cdot01)=0\cdot10612997$. . . . Q.

From p,

$(\cdot2)=0\cdot09810997+0\cdot10612997-0\cdot00100$;

$\therefore (\cdot2)=0\cdot20323994$. . . . . R.

From o,

$(\cdot3)=0\cdot20323994+0\cdot09810997+0\cdot00225$;

$\therefore (\cdot3)=0\cdot30359991$. . . . . S.

From n we get

$(\cdot6)=0\cdot30359991+0\cdot20323994+0\cdot09810997-0\cdot00260$;

$\therefore (\cdot6)=0\cdot60234982$. . . . . T.

Again, adding q and r,

$(\cdot1)=2(\cdot03)+(\cdot02)+2(\cdot01)-0\cdot01409$.

Multiplying s by 2 we get

$2(\cdot03)=2(\cdot02)+2(\cdot01)-0\cdot01284$.

Subtracting u from t,

$(\cdot 2)=2(\cdot 01)-0{\cdot}00531.$

Then $(q+r)+2s+3(t-u)$ gives

$(\cdot 1)=10(\cdot 01)-0{\cdot}04286,$

$\therefore\ 0{\cdot}09810997\ =10(\cdot 01)-0{\cdot}04286,$

$\therefore\ 0{\cdot}009810997=(\cdot 01)-0{\cdot}004286,$

$\therefore\ (\cdot 01)=0{\cdot}014096997.$ . . . . U.

From u we get

$0{\cdot}014096997=(\cdot 01r'')+0{\cdot}00413,$

$\therefore\ (\cdot 01r'')=0{\cdot}009966997.$ . . . . V.

From t we get

$(\cdot 02)=0{\cdot}014096997+0{\cdot}009966997-0{\cdot}00118,$

$\therefore\ (\cdot 02)=0{\cdot}022883994.$ . . . . W.

From s we get

$(\cdot 03)=0{\cdot}022883994+0{\cdot}014096997-0{\cdot}00642,$

$\therefore\ (\cdot 03)=0{\cdot}030560991.$ . . . . X.

From r we get

$(\cdot 06)=0{\cdot}030560991+0{\cdot}22883994+0{\cdot}014096997-0{\cdot}00607,$

$\therefore\ (\cdot 06)=0{\cdot}061471982.$ . . . . Y.

From v we get

$0{\cdot}014096997=(\cdot 01r')+0{\cdot}00410,$

$\therefore\ (\cdot 01r')=0{\cdot}009996997.$ . . . . Z.

The value of the weights thus given was, however, their weight in *air* of the ordinary pressure; it became therefore necessary to ascertain their value in a vacuum. All bodies displace a bulk of air equal to their own volume, and the weight of this air is of course greater as their specific gravity diminishes. In delicate investigations this loss of weight is important. The reduction of the platinum weights to their true value *in vacuo* I calculated by the following formula:—

Let $W=$ weight in air,
$w=$,, ,, water,
$a=$ specific gravity of air as compared with water;

then

$$x\text{, or weight } in\ vacuo,\ =\frac{W-aw}{1-a},$$

where $a=0{\cdot}001225$, and
$1-a=0{\cdot}998775.$

The following Table shows the final results of these adjustments:—

Nominal value of weights.	True value in air at 30 in.* 62° F.	Weight of air displaced.	Volume in water of maximum density.
grs.	grs.	gr.	grs.
1000·00	1000·000000	0·058271	47·5100
600·00	599·998340	0·035533	28·9700
300·00	300·000240	0·017501	14·2700
200·00	199·998910	0·011664	9·5100
100·00	99·991420	0·005887	4·8000
60·00	59·993232	0·003483	2·8400
30·00	29·999991	0·001668	1·3600
20·00	19·999984	0·001104	0·9000
10·00	9·998477	0·000490	0·4000
6·00	5·998268	0·000355	0·2900
3·00	3·000469	0·000171	0·1400
2·00	1·999839	0·000113	0·1000
1·00	0·998980	0·000055	0·0400
0·60	0·602350	0·000035	0·0300
0·30	0·303600	0·000017	0·0200
0·20	0·203240	0·000011	0·0100
0·10	0·098110	0·000005	0·0040
0·06	0·061472	0·000003	0·0030
0·03	0·030561	0·000002	0·0020
0·02	0·022884	0·000001	0·0010
0·01	0·014097	0·000001	0·0004
0·01′	0·009997	0·000001	0·0004
0·01″	0·009967	0·000001	0·0004

The value of each weight in air, plus the weight of air displaced, is, of course, the weight *in vacuo*.

Having ascertained their true value, the weights were carefully preserved; and as, being of platinum, there was no accumulation of tarnish on their surface, and as they were lifted with ivory-tipped forceps to prevent wear, they have showed up to the present time, whenever compared, absolutely no alteration.

The Glass.

The flasks and vessels used were of the hardest Bohemian glass, and as thin as they could be employed. When practicable, vessels of old green German glass were used; neither this nor Bohemian glass is practically affected by reagents.

Liquids were generally kept sealed up in glass bulbs and globes, but sometimes in stoppered green German glass flasks or in "bromine" bottles. When liquids were kept in these bottles for a few days only, they were not found to have contracted any saline impurity from the glass, but after remaining for some weeks they were found to leave a visible residue on evaporation.

No cork or luting was employed in the distillations &c.; in most cases the apparatus was blown in one piece, and the operations performed in a vacuum. The pieces of apparatus which were weighed were entirely composed of glass suspended with platinum loops. The fingers were not allowed to touch them after the first weighing.

The weight of tubes, bulbs, and flasks, even of hard Bohemian glass, constantly diminishes when the glass is long heated in a spirit- or gas-flame; this loss may amount to several thousandths of a grain in the space of two hours when a bulb of Bohemian glass three inches in diameter is exposed to a decided red heat in a gas-flame. Following the suggestion of Professor STAS, I have obviated this source of error by employing a bath of pure magnesia; and find that the weight remains constant even at a nearly white heat. Baths of lime have sometimes been employed with similar satisfactory results.

---

* The cistern of the barometer is 115 feet above the approximate mean water-level at Somerset House.

The special apparatus that I have used will be described in the processes in which they were required; I need scarcely say that in no case were materials of untried purity employed.

Improved Sprengel Vacuum-pump.

[Before detailing the processes of the determination, it will be requisite to describe the means of producing a vacuum in the flasks and bulbs employed. In proceeding with the determinations, several additions and improvements have been made to the Sprengel pump as generally found in the laboratory. Working so much with this pump, I have endeavoured to avoid the inconveniences attending the usual mode of raising the mercury from the lower to the upper reservoir.

The mercury is contained in a closed glass reservoir A (fig. 2, Plate XV.), perforated with a fine hole at the top. This reservoir is attached to a block, capable of free movement in a vertical line, and running in grooves, and connected with the lower reservoir by a flexible tube, *g*.

When the whole of the mercury has run from the reservoir A, the reservoir and slide can be lowered by liberating the teeth of the cog-wheel K from the detent *m*; at the same time a friction-brake is pressed against the cylinder. The aim of this arrangement is to permit the slide-block to fall steadily, swiftly, and without any injurious shock upon the block L. H is a glass reservoir, which receives the mercury after flowing through the pump. When the reservoir A is emptied and has been lowered to the block L, the mercury from H is admitted into A by opening the tap I. *f* is another tap, to regulate the flow of mercury through the pump, whilst a third tap is at R. *g* is a flexible india-rubber tube, strengthened to withstand the pressure by being constructed of concentric layers of rubber and canvas. *b* is a tube filled with small glass beads and containing concentrated sulphuric acid to absorb moisture*; it is attached to *l* by means of a mercury joint. *c*, *c*, *c* are mercury joints, it being inconvenient to have the apparatus in one piece of glass tubing. *e e* is a barometer dipping into the same vessel as the gauge-barometer P, the two thus forming a differential system, by which the rarity of the atmosphere in the apparatus to be exhausted can be easily estimated. *d d* is a scale attached to the gauge.

---

* Since writing the above description I have soldered a small glass tube to the lower part of *b*, turned up and terminating in a funnel-shaped mercury stopper. This enables me to draw off the old acid when weakened by absorption of moisture and to replace it by fresh acid, and also to pass different gases into any apparatus I may have under experiment.—W. C., July 1873.

The reservoir A being filled with mercury, the tap I is turned off and the reservoir is raised to the top of the slide, where it is supported by the piece T.

On opening the tap *f* the mercury rises in the tube *f h*, and falling through the chamber N, carries with it the air contained in the tube R and in the apparatus or bulbs attached to the tube *b*, as in the ordinary Sprengel pump. At N the tubing is enlarged in order that the mercury may not be forced up the tube R, as otherwise frequently happens if the apparatus or mercury gets soiled. This liability of the mercury to run up is further obviated by raising the tube R above the level of the upper reservoir A.

J, J are iron brackets supporting the apparatus. S is a large inverted glass receiver to collect the small portions of mercury which are unavoidably and constantly being spilled; it contains a little weak solution of carbonate of sodium. The part of the tubing *g f h* N forms a barometric siphon arrangement, which effectually prevents air getting into the enlargement N from the reservoir A, when the mercury has completely run out: in this case no harm whatever is done to the operation, the vacuum is not injured, and the exhaustion proceeds immediately on retransferring the mercury from the reservoir H to the reservoir A, and raising A again into its place. The apparatus, as thus arranged, is readily manageable with certainty of obtaining a barometric vacuum.

The mercury fall-tube of a pump in constant use frequently wants cleaning. I find the most effectual means of doing this is to put oil of vitriol into the funnel stopper *h*, and then, by slightly loosening the glass stopper, allow a little of the strong acid to be carried down the tube with the mercury. With care this can be effected without interfering with the progress of exhaustion. The residual acid in the chamber N does good rather than harm. When sufficient sulphuric acid has run into the fall-tube, the funnel stopper can be perfectly closed by filling it with mercury.

The preceding description is that of the apparatus with the most recent improvements. During the determination of the atomic weight of thallium a pump was employed similar in detail, with the exception that, instead of the movable reservoir and flexible rubber tubing, a glass funnel with tubing of glass was used. The mercury passing from the funnel was broken up in its fall and freed from adhering air-bubbles by the insertion of two silk-covered thin iron wires extending from the funnel to the base of the tube. As equally perfect results can be obtained by both methods, the details should be considered as improvements for the sake of convenience rather than for accuracy.—29 *November*, 1872.]

Section III.—THE CHEMICALS.

In this section I shall detail the methods adopted in the preparation of thallium and the reagents in a chemically pure state.

Water.

Ordinary distilled water is mixed with a little crystallized permanganate of silver, and boiled for about half an hour. An excess of sulphuric acid is next added, and it is again boiled for half an hour. The supernatant solution is then transferred to a German green glass retort, and distilled over a water-bath at the rate of about one drop a minute. The end of the neck of the retort is drawn out, and fitted tightly into the mouth of the flask used as a receiver. The first portions of water which distil over are always to be rejected, and the distillation is stopped when about three fourths of the contents of the retort have come over. The product of this distillation is then mixed with freshly precipitated oxide of silver, and allowed to stand, with frequent agitation, until a few drops of the decanted clear solution exhibit an alkaline reaction. The water is then introduced into an apparatus shown at fig. 1, Plate XVI. *a*, *b*, *c* are three globes made of hard German glass, *a* and *c* holding about half a pint each, *b* holding about four ounces; they are connected by tubes as shown, the tubes being contracted at the places *d*, *e*, *f*. The water, containing a little oxide of silver dissolved in it, is introduced through *d* into the globe *a*, until *a* is nearly full. The contracted part at *d* is then sealed up before the blowpipe, the end *g* is put into connexion with the Sprengel pump from which the U-tube containing sulphuric acid has previously been removed, and the mercury set running. Heat is applied to the globe *a* containing the water, until gentle ebullition (under diminished pressure) sets in, the globes *b* and *c* being kept cold with ice. This is continued until no more air, either from the apparatus or from the water, is carried down by the falling mercury. When this is the case, the globe *a* is allowed to cool, and the tube is sealed up at *f*, the vacuum being maintained as perfect as possible. By inclining the tube and globes, any water which may have distilled over from *a* into *b* or *c*, is now poured back into *a*. The two end globes *a* and *c* are then placed in water-baths, whilst the centre globe, *b*, is immersed in melting ice. A gentle heat being applied to the water-bath containing *a*, distillation rapidly proceeds without actual ebullition, and water condenses in *b*, its condensation in *c* being prevented by warming the water-bath in which *c* is immersed. When about one fourth of the contents of *a* has thus distilled over, the operation is stopped, and the bulb *b* removed by sealing the contracted part of the tube at *h*; any trace of ammonia which might happen to be in the water as introduced into *a* will thus have been collected in the bulb *b* and removed. The apparatus now has the appearance shown at fig. 2, Plate XVI. The globe *c* is now cooled in melting ice, and gentle heat being applied to the bath containing the globe *a*, distillation again proceeds, the condensation this time being into *c*. The first portions of water which come over into *c* are used to rinse out that globe, a dexterous movement throwing it all over the inner surface without throwing any of the liquid out of *a*. After two such rinsings, distillation is allowed to proceed without ebullition until four fifths of the water has distilled from *a* to *c*. The tube is then sealed at the contracted part *e*, and the globe *c* (fig. 3), containing what I believe to be absolutely pure water *in vacuo*, may be set aside for future use. It will be observed that the water, almost chemically pure to begin with, has in this manner been distilled and further purified in the entire absence of atmospheric air. When some of this water is required for use, the glass tube is touched at *f* with a blowpipe-flame. As soon as the glass softens, the atmospheric pressure forces the glass in, forming a fine hole. In this way no fragments of glass get into the water, as might be the case if the end of the tube were broken off after scratching with a file in the usual manner. As much water as is needed is driven out by warming the globe, and the water remaining unused may be sealed up again.

Water purified in this manner was employed in the final crystallizations of all the salts used in the investigation, in rinsing out the apparatus, and generally in all operations where its employment was likely to increase the accuracy of the result.

Nitric Acid.

The apparatus in which the nitric acid was prepared is represented in the accompanying figure (fig. 4, Plate XVI.). *a*, *b*, *c*, *d* are glass globes, *a* being about 4 inches and the others about 2 inches diameter; they are connected by fusion with glass tubes bent as represented in the drawing, and contracted at the points *o*, *p*, *q*, *r*, *s*. The cylindrical tube *e* is connected by means of a flexible joint, *i i i i* (fig. 4 *b*), to the Sprengel pump: this joint consists of several pieces of glass tube held closely together by means of india-rubber tubing; the pieces of tubing are fastened with two or three turns of silk-covered iron wire. A little glycerin smeared over a joint of this description renders it quite air-tight, whilst the apparatus is capable of considerable movement. A mixture of glacial phosphoric acid and nitrate of silver in atomic proportions, and coarsely ground together in an agate mortar, is introduced into the globe *a* until about half-full, the cylinder *e* having previously been filled through the opening *g* with pieces of caustic soda. The tubes *f* and *g* are now sealed up at the contracted portions, and the Sprengel pump is connected to *h*. Exhaustion is proceeded with, the apparatus being gently warmed at the same time until moisture is no longer visible, and the mercury is as high as the vapours present will allow it to rise. The bulb *b* is then immersed in a freezing-mixture, and heat is cautiously applied to the bulb *a*. The nitrate of silver and phosphoric acid soon fuse together to a clear liquid, and vapours of nitric acid mixed with nitrous acid are copiously evolved. The mixture froths considerably, and care must be taken that none rises so high as to pass into the bulb *b*. In this and the other bulbs nearly all the vapours condense, the small quantity that escapes being caught by the caustic soda in *e*. If, through spirting or inadvertence, some of the solid matter is carried over from *a* into *b*, the contents of *b* are easily decanted back into *a* by tilting the apparatus into such a position that the line *k l* would become horizontal: owing to the curvatures of the connecting-tubes, no liquid which might be in the bulbs *c* or *d*, and none of the pieces of caustic soda in *e*, can get out of their place. When the reaction between the phosphoric acid and nitrate of silver has been pushed as far as convenient (too strong a heat must not be applied, or the nitric acid is in part decomposed as it is liberated), the tube connecting *a* and *b* is sealed in a spirit-lamp, and the globe *a* drawn off. The bulb *c* is now thoroughly washed out with nitric acid by distilling a little over from *b*, letting it condense in *c*, and then pouring it back by inclining the apparatus so that the vertical line *m n* would become horizontal. The bulbs *b* and *d* are now warmed in water-baths, whilst the bulb *c* is immersed in a freezing-mixture. Distillation rapidly proceeds without ebullition, the acid almost entirely condensing into *c*. When about four fifths of the contents of *b* are distilled into *c*, the tube is sealed up at *q* before the blowpipe and the bulb *b* drawn off.

The next operation is to clear the acid in *c* and the rest of the apparatus from nitrous vapours. For this purpose the mercury of the Sprengel pump is set gently in motion, and the apparatus is very moderately heated from time to time until the vacuum is as perfect as the tension of nitric-acid vapour will admit*. When this is effected, the bulb *c* is gently warmed in a water-bath, whilst *d* is immersed in a freezing-mixture. The temperature of *c* is so adjusted that distillation proceeds slowly without ebullition. When four fifths of the contents of *c* have come over, the mercury-pump working slowly all the time, the connecting-tube is sealed before the blowpipe at *r*, and *c* is drawn off. The flame being then applied at the contracted part *s*, the bulb *d*, containing the pure nitric acid, and having the appearance shown at Plate XVI. fig. 4 *a*, is removed. The acid may be kept unchanged for any length of time, provided it be not exposed to the light. When required for use, the end of one of the tubes is perforated with a blowpipe-flame, as described above under the heading "Water." By heating the bulb, any desired quantity of acid is driven out, when the remainder can again be sealed up.

Oxalic Acid.

Commercial purified oxalic acid is gently heated in a flat dish until the water of crystallization is removed. Bibulous paper is then placed over it, a paper cap over that, and the heat is increased until the oxalic acid sublimes. The sublimed crystals are removed from the inside of the paper cap, and introduced into the lower portion, *a*, of the glass apparatus shown in the diagram (Plate XVI. fig. 5). The tubes are contracted at *b* and *c*, and the end *d* is connected by means of an india-rubber connector with the Sprengel pump. The air is now completely exhausted from the apparatus, and it is immersed in a paraffin-bath to a little above the first contraction, *b*; a thermometer is also immersed in the bath.

The temperature is first raised to 200° F., and the exhaustion continued until all moisture disappears from the inside of the tube. The bath is then gradually raised to 250°, and kept at that temperature till the oxalic acid has risen in vapour and condensed in the wide portion of the tube between *b* and *c*. The paraffin-bath is then taken away, and when the tube is cold it is removed from the pump by applying a blowpipe-flame to the contraction *c*; this being repeated at *b*, leaves the sublimed oxalic acid perfectly pure in the bulb *b c*, and in a vacuum.

In this apparatus oxalic acid commences to sublime below 200° F. If the temperature of the paraffin-bath be kept below 278° F. no permanent gas is evolved, and no formic acid is obtained; above that temperature the barometer-gauge of the pump commences to sink; but the mercury descends very slowly until 330° is reached, when the decomposition of the oxalic acid into formic and carbonic acids becomes more rapid.

---

* If acid vapours pass into the tubes of the Sprengel pump they do no harm, being carried down at once. The small quantity which condenses in the tubes may be afterwards removed by passing some distilled water through the pump, and then drying with warm air, or by passing oil of vitriol through the pump.

Sulphuric Acid.

After many attempts to prepare sulphuric acid free from arsenic by the distillation at a red heat of alkaline bisulphates, by dissolving sulphuric anhydride in water, and by decomposing sulphate of silver with sulphuretted hydrogen, I finally adopted Bloxam's method of preparing it by means of sulphurous and nitrous acids (Journ. Chem. Soc. vol. xv. p. 52).

The sulphurous acid is evolved from well-crystallized sulphite of sodium by the action of sulphuric acid, keeping the temperature as low as possible. The current of gas is first passed through a washing-bottle of water containing a little oxide of silver in suspension (which becomes converted into sulphite of silver, and then into a mixture of sulphate of silver and metallic silver), then through two U-tubes filled with small pieces of pumice-stone moistened with water. The pumice-stone should be previously purified from chlorides and fluorides by Stas's method of igniting it twice with sulphuric acid.

The nitrous acid is prepared by gently heating together nitrate of potassium, ferrous sulphate (both purified by repeated crystallization), and dilute sulphuric acid.

The sulphurous acid and nitrous acid are conducted simultaneously by tubes into a large glass globe, a third tube serving for the introduction of steam. The three tubes pass into the globe through a glass plate in which three holes have been perforated. The glass plate and mouth of the glass globe are fitted to each other by grinding. No lute being used, sufficient air finds its way into the globe to keep up the reaction. By regulating the ingress of nitrous acid, of sulphurous acid, and of steam, the operation can be carried on continuously for many hours.

The condensed liquid is next introduced into an apparatus blown from hard German glass, as shown in Plate XVI. fig. 6. *a*, *b*, and *c* are three bulbs about 3 inches diameter. The dilute sulphuric acid is introduced into the bulb *a* by means of the neck *d*, which is then sealed before the blowpipe at the contracted part. The end of the tube *e* is then connected with the Sprengel pump, the end *f* temporarily stopped up, and the whole is exhausted. The bulb *b* is immersed in a water-bath kept at the boiling-point, and *a* being gently heated the excess of water in the sulphuric acid goes off, and partly condenses in the bulb *c*, which is kept cold, and partly becomes carried down through the pump by the falling mercury.

Concentration of the acid proceeds rapidly; and as soon as all excess of water has been thus eliminated, and the gauge of the pump shows that only aqueous vapour is present, the bulb *c*, containing water, is removed by applying a blowpipe-flame to the contracted portion of the tube *g*. Air is now admitted, the tube *f* is connected with the Sprengel pump, and exhaustion again proceeded with. The bulb *b* is now kept cool, and the bulb *a* heated in a sand-bath. The atmospheric pressure must not be altogether removed, or the bumping of the acid in *a* will be very violent. If the exhaustion is such that the mercury in the gauge stands at about 15 inches, the oil of vitriol distils quietly from the bulb *a* to *b* without bumping; but if the exhaustion is raised to above 16 inches, the ebullition becomes percussive. When most of the acid has distilled over into *b* the source of heat is removed, the mercury in the pump is again allowed to run until a vacuum is produced, and the bulb *b*, containing pure distilled sulphuric acid, is sealed up and removed by the application of a blowpipe-flame to the contracted portions of the tubes *h* and *i*.

Carbonic Acid.

Calc-spar is dissolved in pure hydrochloric acid. An excess of the spar is added, and the solution warmed; to it is added lime-water made from pure or nearly pure lime, until the solution is alkaline to test-paper. This solution is filtered, and after heating it to at least 160° F., precipitated with carbonate of ammonium*. The carbonate of calcium thus precipitated is thrown on a filter and well washed with pure water. Thus prepared, the carbonate of calcium is a dense powder and perfectly pure; or, if it contain any impurity, it will be a trace of carbonate of barium or strontium, which in no way interferes with its use in preparing carbonic acid.

The dense granular carbonate of calcium is then strongly compressed in a steel diamond mortar into the form of coherent lumps. These lumps are introduced into a WOULFE's bottle, and pure oil of vitriol poured over them. A continuous and not too rapid evolution of carbonic acid commences and is continued for some time. When the disengagement of gas becomes sluggish, a few drops of water restore the action. Large bottles must be used for this operation to avoid the inconvenience of the foaming to which the acid is liable.

The carbonic acid is washed by passing through solution of sulphate of silver containing carbonate of silver in suspension to the consistency of thin cream, and it is then passed through a U-tube containing purified pumice-stone moistened with oil of vitriol.

Ammonia.

Ammonia is prepared in two ways:—

1. Nitrate of potassium heated to incipient decomposition, and then crystallized three times from pure water, is dissolved to saturation in water, and put into a retort. Sodium amalgam containing about 1 per cent. of sodium is then added, and the whole allowed to stand in a cool place for twelve hours. Gentle heat being now applied to the retort, ammonia (from the reduction of the nitric acid) is driven over with the first

---

* This precaution, which was first suggested by Professor J. LAWRENCE, of Louisville, must not be overlooked, as it is desirable to obtain the precipitated carbonate of calcium as dense as possible. If the carbonate of ammonium be added to the cold solution, the precipitate, at first gelatinous, will ultimately become much more dense and settle readily; the same is true if the mixture be heated after the addition of the carbonate of ammonium; but in neither case will it be as dense as when the carbonate is added to the hot solution of chloride of calcium.

portions of water, and is condensed in a receiver cooled with ice. The temperature of the liquid in the retort is not allowed to rise to the point of ebullition, and the operation is stopped when one fourth of the liquid in the retort has distilled over.

2. Ammonia is also prepared by a method recommended by Professor STAS. Nitrite of potassium is mixed with strong solution of caustic potash, and the liquid poured into a large glass balloon containing a mixture of zinc (free from carbon*) and iron wire which has been first oxidized by heating in the air and then reduced by hydrogen. After standing for seventy-two hours, the liquid is decanted from the residue into a retort, which is then gently heated on a sand-bath. The arrangement for condensing the ammonia consists of two flasks fitted up as WOULFE'S bottles containing pure water. The distillation is effected very slowly below the boiling-point of the liquid, and the condensers are cooled with ice.

Hydrogen.

The method pursued in the preparation of pure hydrogen is as follows:—The gas is generated in one of a series of WOULFE'S bottles by pouring warm caustic potash over a mixture of granulated zinc and iron scraps. The gas thus generated (the method is due to RUNGE, POGG. Ann. xvi. p. 130) is inodorous. It is next passed into another WOULFE'S bottle containing protochloride of tin; then through tubes containing pumice-stone moistened with a concentrated solution of pyrogallic acid in caustic potash, and again through tubes containing pumice moistened with sulphuric acid, the object in passing the gas through the protochloride of tin and through the pyrogallic acid being to remove the oxygen diffused into the apparatus from the atmosphere.

Thallium.

It may not be out of place here to note the most usual sources of thallium as it is ordinarily prepared.

Thallium is a very widely distributed constituent of iron and copper pyrites. Upon examining a large collection of pyrites from different parts of the world, it was found present in more than one eighth. It is not confined to any particular locality. Amongst those ores in which it occurs most abundantly (although in these cases it does not constitute more than from the 100,000th to the 4000th of the bulk of the ore), may be mentioned iron pyrites from Theux, near Spa in Belgium, from Namur, Philipville, Alais, the south of Spain, France, Ireland, Cornwall, Cumberland, and different parts of North and South America; in copper pyrites from Spain, as well as in crude sulphur prepared from this ore; in blende and calamine from Theux; in blende, calamine, metallic zinc, sulphide of cadmium, metallic cadmium, and cake sulphur from Nouvelle-Montagne; in native sulphur from Lipari and Spain; in bismuth, mercury, and antimony ores, as well as in the manufactured products from these minerals (frequently in so-called pure medicinal preparations of these metals); in commercial selenium and tellurium (probably as selenide and telluride).

---

* Zinc is obtained free from carbon by fusing it with a mixture of carbonate of sodium and nitre.

Thallium is likewise frequently present in copper and commercial salts of this metal. In Spain a very impure copper is prepared in the following way:—Copper pyrites is allowed to oxidize in the air, and the resulting sulphate of copper is washed out; scrap iron is now placed in the liquid, which causes the copper to precipitate in the powdery state. The metal is then collected together, dried, strongly compressed, and heated to the melting-point. It is brought over to this country in the form of rectangular cakes, weighing about 20 lbs. each, and is called "cement copper." The sulphide of thallium, oxidizing to sulphate along with the sulphide of copper, is washed out by the water, and precipitated with the copper by the iron. The two metals alloy together.

Thallium is present in tolerable quantity in lepidolite from Moravia, and in mica from Zinnwald. It has likewise been found in the deliquescent "sel à glace" from the mother-liquors of the salt-works at Nauheim. This consists of a mixture of the chlorides of magnesium, potassium, and sodium, with relatively considerable quantities of chlorides of rubidium and cæsium, and sensible traces of chloride of thallium. Thallium is also met with in the mother liquors in the sulphate-of-zinc works at Gozlar, in the Harz.

Nordenskjöld has found in the copper-mine of Skrikerum, in Norway, a native selenide of copper, silver, and thallium, containing about 18 per cent. of thallium. It occurs in the form of lead-grey compact masses, having the hardness of copper glance and a spec. grav. of 6·9. This mineral has been named *Crookesite* by its discoverer. From the general association of selenium, copper, silver, and thallium in iron and copper pyrites it is probable that the thallium is here present in the form of Crookesite disseminated through the mass.

The optical process of detecting thallium in a mineral is very simple. A few grains of the ore are crushed to a fine powder in an agate mortar, and a portion taken up on a moistened loop of platinum wire. Upon gradually introducing this into the outer edge of the flame of a Bunsen's gas-burner, and examining the light by means of a spectroscope, the characteristic green line will appear as a continuous glow, lasting from a few seconds to half a minute or more, according to the richness of the specimen. By employing an opaque screen in the eyepiece of the spectroscope to protect the eye from the glare of the sodium line, thallium may be detected in half a grain of mineral, when it is present only in the proportion of 1 to 500,000. The sensitiveness of this spectrum reaction is so great that no estimate can be arrived at respecting the probable amount of thallium present.

Many samples of commercial sulphuric acid and yellow hydrochloric acid contain thallium. The source in these cases is evidently the pyrites used in the sulphuric-acid works.

PREPARATION OF COMMERCIALLY PURE THALLIUM.

a. From the Flue-dust of Pyrites-burners.—This is by far the most economical source of thallium at present known. In burning thalliferous pyrites for the purpose of manufacturing sulphuric acid, the thallium oxidizes along with the sulphur, and is driven off by the heat. If the passage leading from the burners to the leaden chambers is only a few feet long, the greater portion of the thallium escapes condensation, and is carried into the leaden chambers; it there meets with aqueous vapours, sulphurous and sulphuric acids, and becomes converted into sulphate of the protoxide of thallium. This being readily soluble both in water and dilute sulphuric acid, and not being reduced by contact with the leaden sides, remains in solution and accompanies the sulphuric acid in its subsequent stages of concentration, &c. If, on the other hand, the passage connecting the burners and chambers is 10 or 15 (or more) feet in length, nearly the whole of the thallium is condensed, together with the multiplicity of other bodies which constitute "flue-dust." Accompanying the thallium have been found mercury, copper, lead, tin, arsenic, antimony, iron, zinc, cadmium, bismuth, lime, and selenium, together with ammonia, sulphuric, nitric, and hydrochloric acids. The amount of thallium in these flue-deposits is very various: in many specimens it is not present at all, and in very few it amounts to as much as $\frac{1}{4}$ per cent., although in some as much as 8 per cent. of thallium has been found.

The following is the best plan for extracting thallium from the dust:—The dust is first heated to very dull redness, so as to allow the excess of sulphuric acid to drive off any hydrochloric acid which may be present, and is then mixed in wooden tubs with an equal weight of boiling water, and well stirred; after this the mixture is allowed to rest for twenty-four hours for the undissolved residue to deposit. The liquid is then siphoned off, and the residue is washed, and afterwards treated with a fresh quantity of boiling water. The collected liquors which have been siphoned off from the deposit are allowed to cool, precipitated by the addition of a considerable excess of strong hydrochloric acid, and the precipitate, consisting of very impure chloride of thallium, is allowed to subside. The chloride obtained in this way is then well washed on a calico filter, and afterwards squeezed dry. Three tons of flue-dust treated in this way yielded as much as 68 lbs. of this crude chloride.

The next step consists in treating the crude chloride in a platinum dish with an equal weight of strong sulphuric acid, and afterwards heating the mixture to expel the whole of the hydrochloric acid. To make sure of this, the heat must be continued until the greater part of the excess of sulphuric acid is volatilized. After this the mass of bisulphate of thallium is dissolved in about twenty times its weight of water, nearly neutralized with chalk, and then filtered. On the addition of hydrochloric acid to the filtrate, nearly pure chloride of thallium is thrown down; this is collected on a filter, well washed, and then dried. The crude protochloride of thallium obtained by either of the above methods is added by small portions at a time to half its weight of hot oil of vitriol in a porcelain or platinum dish, the mixture being constantly stirred and the heat continued till the whole of the hydrochloric acid and the greater portion of the excess of sulphuric acid are driven off. The fused bisulphate is now to be dissolved in an excess of water, partially neutralized with carbonate of sodium, and an abundant stream of sulphuretted hydrogen passed through the solution. The precipitate, which may contain tin, arsenic, antimony, bismuth, lead, mercury, and silver, is separated by filtration, and the filtrate is boiled till all free hydrosulphuric acid is removed. The liquid is now to be rendered alkaline with ammonia and boiled; the precipitate of iron and alumina, which generally appears in this place, is filtered off, and the clear solution evaporated to a small bulk. Sulphate of thallium will then separate out on cooling in the form of long, clear prismatic crystals. As sulphate of ammonium is much more soluble than sulphate of thallium, the latter can readily be separated from the small quantity of the former salt present. The two salts do not crystallize together.

In order to avoid the inconvenience of driving off the excess of oil of vitriol in the decomposition of chloride of thallium, it is less troublesome, although not quite so economical, to proceed as follows:—Boil the chloride of thallium in solution of sulphide of ammonium for five minutes: decomposition takes place readily. Filter and wash with sulphuretted water till no more chlorine can be detected in the filtrate; then dissolve the sulphide on the filter in dilute sulphuric acid, and treat the solution with ammonia &c., as above directed.

In order to obtain the metal when working on small quantities of material, sulphate of thallium is dissolved in twenty times its weight of water; the liquid is acidulated with sulphuric acid, and a current of electricity from two or three cells of GROVE's batteries is passed through it, platinum terminals being used. The appearance presented when a tolerably strong solution of thallium is undergoing reduction is very beautiful. If the energy of the current bears a proper proportion to the strength and acidity of the liquid, no hydrogen is evolved at the negative electrode, but the metal grows from it in large crystalline fern-like branches, spreading out into brilliant metallic plates, and darting long needle-shaped crystals, sometimes upwards of an inch in length, towards the positive pole, the appearance being more beautiful than with any other metal. Some of the tabular crystals, as seen in the liquid, are beautifully sharp and well defined; considerable difficulty, however, is met with in disengaging them from the electrode, and removing them in a perfect state from the liquid. So long as thallium is present in the solution, no hydrogen is evolved with a moderate strength of current; as soon as bubbles of gas are evolved, the reduction may be considered complete. The crystalline metallic sponge may now be squeezed into a mass round the platinum terminal, disconnected from the battery, quickly removed from the acid liquid, rinsed with a jet from a wash-bottle, and transferred to a basin of pure water. The metal is then carefully removed from the platinum, and kneaded with the fingers into as solid a lump as possible. It coheres readily by pressure, and will be found to retain its metallic lustre perfectly under water.

When considerable quantities of thallium are to be reduced to the metallic state, it is convenient to employ metallic zinc for the purpose. In the course of twenty-four hours I have reduced upwards of a quarter of a hundredweight of the metal in the following way:—Plates of pure zinc (which should leave no residue whatever when dissolved in sulphuric acid) are arranged vertically round the sides of a deep porcelain dish holding a gallon. Crystallized sulphate of thallium, in quantities of about seven pounds at a time, is then placed in the dish, and water poured over to cover the salt. Heat is applied, and in the course of a few hours the whole of the thallium will be reduced to the state of a metallic sponge, which readily separates from the plates of zinc on slight agitation. The liquid is poured off, the zinc removed, and the spongy thallium washed several times. It is then strongly compressed between the fingers, and preserved under water until it is ready for fusion.

The metal is readily obtained in the coherent form by fusing the sponge. This is most conveniently performed under cyanide of potassium on the small scale, and under coal-gas when working with large quantities. In the former case the sponge, strongly compressed and quite dry, is broken into small pieces, which are dropped one by one into cyanide of potassium kept fused in a porcelain crucible. They rapidly melt, forming a brilliant metallic button at the bottom. When cold, the cyanide of potassium may be dissolved in water, when the thallium will be left in the form of an irregular lump, owing to its remaining liquid and contracting after the cyanide has solidified.

On the large scale, the fusion is best effected in an iron crucible. This is placed over a gas-burner, and a tube is arranged so that a constant stream of coal-gas may flow into the upper part of the crucible. Lumps of the compressed sponge are then introduced, one after the other as they melt, until the crucible is full of metal. It is then stirred up with an iron rod; and the thallium may either be poured into water and obtained in a granulated form or cast into an ingot. Thirty or forty fusions have been performed in the same crucible without the iron being appreciably acted upon by the melted thallium.

b. From Iron Pyrites.—The richest pyrites which I have yet met with comes from Oneux, near Theux; it contains about 1 part of thallium in 4000. Two tons of this ore were worked in the following manner:—

The pyrites, broken up into pieces of the size of a walnut, is distilled in hexagonal cast-iron pipes, closed at one end, and arranged in a reverberatory furnace. Conical sheet-iron tubes are luted on to the open ends, and the retorts are kept at a bright red heat for about four hours. At the end of the operation the receivers are found to contain from 14 lbs. to 17 lbs. of dark green or grey-coloured sulphur for every 100 lbs. of ore used. The whole of the thallium originally in the pyrites will be found in this sulphur, from which it has now to be separated. The sulphur may be dissolved out by means of bisulphide of carbon, which leaves the sulphide of thallium behind; or it may be extracted by boiling with caustic soda. The former plan occasions less loss of thallium, but, owing to the inconvenience of working with large bulks of bisulphide of carbon, the soda process is preferable. 12 lbs. of caustic soda, 18 lbs. of the thalliferous sulphur, and 1½ gallon of water are boiled together till the sulphur has dissolved; 6 gallons of water are added, and the clear liquid, when cool, is decanted from a voluminous black precipitate, which has been separated from the sulphur. The precipitate is then collected on a calico filter and washed. It contains the greater portion of the thallium in the form of sulphide, together with iron, copper, mercury, zinc, &c. Some thallium, however, remains dissolved in the alkaline liquid, and is lost. The black precipitate is then dissolved in hot dilute sulphuric acid, to which a little nitric acid is added, and the liquid is diluted with water and filtered. Hydrochloric acid and a reducing agent, such as sulphite of sodium, will now throw down the nearly insoluble white protochloride of thallium, which is to be filtered off and washed.

c. From Sulphur or Pyrites in the Wet Way.—The material is boiled in nitro-hydrochloric acid until nothing but bright yellow sulphur is left; water is then added, and the filtrate is evaporated with sulphuric acid until it is nearly dry, and sulphuric vapours are copiously evolved. The residue is dissolved in a large excess of hot water, and carbonate of sodium is added to alkaline reaction, and then cyanide of potassium (free from sulphide of potassium). The liquid is then heated gently for some time, and filtered. The precipitate contains the whole of the lead and bismuth which may be present, as carbonates, whilst the thallium is in solution. A current of sulphuretted hydrogen being now passed through the alkaline liquid precipitates all the thallium, whilst the copper, antimony, tin, and arsenic remain dissolved. The precipitated sulphide is filtered off, washed, and dissolved in dilute sulphuric acid, and the thallium is precipitated by means of hydrochloric acid as chloride, from which the metal is extracted in the way previously described.

d. From the Saline Residues of the Salt-works at Nauheim.—Dr. Böttger adds an insufficient quantity of bichloride of platinum to the strong solution, and boils the precipitate five or six times with three times its weight of water. The insoluble residue consists of the platinum-salts of cæsium, rubidium, and thallium. Upon boiling these with a weak solution of potash and a little hyposulphite of sodium, the solution soon becomes clear, whereupon cyanide of potassium and sulphuretted hydrogen are added. This precipitates the thallium as sulphide. The liquid is then to be filtered, the residue washed and dissolved in sulphuric acid, and the metal precipitated by metallic zinc.

e. From Commercial Hydrochloric Acid.—Many samples of yellow hydrochloric acid contain thallium. It may be separated by neutralizing with an alkali and adding sulphide of ammonium. The black precipitate contains the thallium, together with iron and some other metallic impurities of the acid. It is to be dissolved in sulphuric acid, and the thallium precipitated with hydrochloric acid as protochloride. This is afterwards reduced as already described.

f. From the Mother-liquors of the Sulphate-of-Zinc Works at Goslar.—Each kilogramme of these liquors is said to yield as much as half a gramme of chloride of thallium. A sheet of zinc is plunged into the liquid, whereby the thallium, copper, and cadmium are precipitated. The metallic sponge is then removed from the zinc, washed, and treated with cold dilute sulphuric acid, which dissolves the cadmium and thallium with disengagement of hydrogen, whilst the copper is left behind. The filtrate from the copper is then mixed with hydrochloric acid, which precipitates the nearly insoluble chloride of thallium. If only a small quantity of thallium is present, iodide of potassium may be used as a precipitant, as the iodide of thallium is insoluble in water.

PREPARATION OF CHEMICALLY PURE THALLIUM.

a. Commercial sulphate of thallium is dissolved in water, and the cold solution deluged with sulphuretted hydrogen. It is then filtered, heated to ebullition, and poured into boiling dilute hydrochloric acid. The solution is filtered whilst hot and then allowed to cool. The chloride of thallium which crystallizes out on cooling is washed by decantation until the washings are free from sulphuric acid, and further purified by recrystallizing twice from water. The chloride of thallium thus obtained is dried, mixed with pure carbonate of sodium, and projected by small portions at a time into pure cyanide of potassium kept in a state of fusion in a white unglazed crucible. The chloride is rapidly reduced to the metallic state; the crucible is then allowed to cool, and the contents exhausted with water. The resulting ingot of metal is well boiled in water, dried and fused over a spirit-lamp* in an unglazed porcelain crucible with free access of air, stirred with a porcelain rod to facilitate oxidation, and finally cast in a porcelain mould. It may be preserved under water which has been boiled to expel the air. This metal was used in the determinations A and B.

b. Ordinary metallic thallium is fused in contact with the air, in an iron crucible made nearly red-hot, and then poured into water. The granulated metal is then exposed to a warm atmosphere to facilitate oxidation, the oxide being frequently removed by boiling out with water. When a considerable quantity of oxide (mixed with carbonate) has been obtained, the solution is heated to ebullition, and a rapid current of carbonic-acid gas passed through until the liquid is quite cold, and the excess of carbonate of thallium has crystallized out. The resulting salt is recrystallized and projected into pure cyanide of potassium kept in a state of fusion in a porcelain crucible at a dull red heat; carbonic acid escapes with effervescence, and the metal is reduced to the metallic state. The whole is then allowed to cool, the soluble salts boiled out with water, and the lump of thallium fused over an alcohol-lamp in a lime crucible and cast in a lime mould as described further on. With this ingot of thallium the determination C was effected.

c. Carbonate of thallium, obtained as in process *b*, is covered with a small quantity of water, and decomposed by the current from six GROVE'S cells. Much peroxide of thallium is deposited, which is removed† and preserved for the preparation of thallium by another method. The reduced thallium is then squeezed into a hard cake, melted in a lime crucible heated by means of a spirit-lamp, and cast in a lime mould. This metal was employed in the determination D.

d. A third portion of carbonate of thallium, obtained as in process *b*, is crystallized several times from water, carbonic acid being passed through during the cooling of the solution. After six crystallizations the carbonate is perfectly white. It is then placed in a porcelain dish, covered with a little water, and decomposed by four GROVE'S cells.

---

* A spirit-flame is preferable to one of coal-gas, as the latter contains sulphur.

† The operation requires this peroxide of thallium to be constantly removed from the positive pole, or the passage of the current will be retarded and ultimately stopped.

The spongy metal is washed, boiled in pure water, tied up in a linen cloth, and compressed between steel plates in a vice. The hard lump is broken up, put into a porcelain crucible and melted over a spirit-lamp, no flux being used other than the thallium oxide formed on heating. The metal is constantly stirred with a piece of unglazed porcelain and cast in a warm porcelain mould. With thallium prepared in this manner the synthetical operations E and F were performed.

e. The peroxide of thallium obtained by the electrolysis of the carbonate (processes *c* and *d*) is dissolved in purified sulphuric acid, evaporated to dryness, and heated strongly to decompose any sulphate of peroxide; it is then dissolved in water and recrystallized twice. The sulphate of thallium is then reduced to the metallic state by three of GROVE's cells, platinum terminals being employed. The metal is squeezed into a lump and melted under hydrogen in a porcelain crucible, and cast in a polished steel mould, the heat in this case being produced by the combustion of pure hydrogen gas. The thallium purified as above was used in the operation G.

f. Chloride of thallium, as obtained by method *a*, is boiled in nitric acid till most of it is converted into sesquichloride. This is washed by decantation until it begins to decompose with separation of peroxide of thallium, and purified by twice recrystallizing. The purified sesquichloride of thallium is dissolved in boiling water and poured into dilute ammonia. The precipitated peroxide of thallium is washed by decantation till chlorine is no longer detected in the washings, and then boiled in a little water with pure sublimed oxalic acid till the whole is converted into oxalate of thallium. This is dried and heated in a crucible until the whole is decomposed into a mixture of metallic thallium and oxide of thallium; the reduced metal is then cast in a mould of polished steel. The ingot was employed in the determination H.

g. Ordinary thallium is dissolved in nitric acid, and the excess of acid driven off by heat, the residue is dissolved in water, and the solution saturated with sulphuretted hydrogen. A slight black precipitate is generally formed, the solution is filtered cold, and is then freed from sulphuretted hydrogen by boiling. Ammonia is then added, which generally produces a faint precipitate of sesquioxide of iron and peroxide of thallium; it is then filtered, and the solution is mixed with oxalate of ammonium and concentrated till the oxalate of thallium crystallizes out. This is freed from nitrate of ammonium by recrystallizing, and the oxalate of thallium decomposed by heat, as in process *f.* The thallium thus obtained is again fused in a lime crucible, a blowpipe-flame being directed downwards on to the surface of the fused metal for about five minutes, till the slag of thallium oxide has united with the lime, forming a semifluid pasty mass. The metal is then cast in a lime mould, washed when cold, and kept under boiled distilled water or very dilute acetic acid. With metal purified in this manner the estimations I and K were performed.

Purification of Thallium by Fusion in Lime.

A piece of well burnt, very dense quick-lime, prepared from black marble, is cut out so as just to fit a porcelain crucible; a hole is then turned in the centre of the lime, and a lump of lime cut into the form of a stopper. This apparatus is then raised to a temperature above the melting-point of thallium over a spirit-lamp, and the cavity in the lime is gradually filled with the metal, previously purified by one of the above processes, which is introduced in lumps. The stopper is then put on, and the heat raised to dull redness and kept so for half an hour; after which the melted metal is poured into a lime mould, and preserved in a well-stoppered bottle under boiled water or very dilute acetic acid.

The ingots of thallium purified by the various methods above described were kept separate, and were employed in the synthetical operations described further on.

Section IV.—PROCESSES AND RESULTS.

The processes and manipulation necessary to the determination of an atomic weight are at all times difficult and delicate, but especially so in the case of a metal such as thallium, so readily oxidizable. This strong tendency to combine with oxygen renders the ordinarily exact processes of weighing out pure metals inapplicable to the present purpose. The chances of contact with the oxygen of the atmosphere must be reduced to a minimum, and to this end the following modes of operation were devised. The method found to be the most accurate, and that adopted in repeating the determinations, will receive a description more detailed than the first and what may be termed approximative methods.

Process of the Conversion of Thallium into Nitrate of Thallium.

Thallium being a metal of very high atomic weight, the change in weight in the interconversion of its compounds is comparatively too small to be estimated with any approximation to accuracy. For instance, the conversion of acetate of thallium into chloride of thallium is an operation hardly to be effected without such loss as would seriously interfere with the calculated result*. The immediate conversion of the metal into one of its salts is therefore the method affording results less liable to be affected by errors in observation; and the conversion of thallium into its nitrate has been that ultimately adopted.

Pure thallium, obtained as described, is cut up into small bars with a very sharp steel knife, and dropped into a dish of pure water slightly warmed, and forming the substratum to an atmosphere of carbonic acid in a vessel large enough to admit both hands easily. In this bath the original surface of the ingot is removed and rejected. The bars are then well rubbed with fine cambric to smooth down all sharp edges. Any pieces which contain pores are rejected†.

A stoppered tube (Plate XVI. fig. 7) is half filled with water and weighed. The bars of thallium are then quickly removed from the warm water of the carbonic-acid bath, rapidly wiped dry with warm cambric while in the carbonic acid, and put into the weighed tube of water. It is found that no appreciable oxidation takes place during this transference, and that the whole of the moisture can be removed. The tube and its contents are then weighed again.

---

* An error of 0·05 grain in the weighing accumulates to an error of 0·95 in the atomic weight.

† The upper surface of the fused lump is full of pores for a depth of one sixteenth of an inch; one quarter inch is therefore removed for greater certainty.

Fig. 8 represents a vessel for the conversion of thallium into its nitrate, the pure metal as weighed in the manner described above in a tube of water being placed in the bulb *a*, and the pure nitric acid in *b*. The tubes are accurately ground and fitted to each other at *c*. *d* is a permanent stopper to the upper bulb, well ground. *e* and *f* are platinum wires for the support of the flask in the balance. The process of converting the thallium into its nitrate coincides in detail with this apparatus with the process ultimately adopted, and particularly described in the succeeding pages. With an apparatus of this kind the determination A was performed, the metal being purified by the process already described under *a* (p. 308).

Fig. 9 is a further improvement. The nitric acid in acting upon the metal in *a* evolves fumes, which mechanically carry off traces of nitrate of thallium. In the vessel shown in fig. 8 these fumes are washed in the nitric acid, offering, however, no great advantage; but in the series of bulbs shown in fig. 9, *b* contains the nitric acid, which can, by means of the tap *c*, be admitted in the required quantity to the metal. The fumes are washed in the water contained in *g*, the water being evaporated to obtain the nitrate of thallium held in solution. In this apparatus, and with metal purified by the process described under the letter *a*, the determination B was effected. The metallic thallium is weighed sealed up in hydrogen in the following manner:—

The lump or ingot of pure metallic thallium prepared by the process *a*, already described, is cut up into parallelograms, all the original surface being removed with a very sharp steel knife. The parallelograms, immersed and boiled in very dilute sulphuric and hydrochloric acids, are subsequently washed, boiled repeatedly in water, and then transferred to the glass tube *a*, fig. 10. Into this tube pass and are fused the platinum wires *b*, *c*, these wires being the reducing and oxidizing electrodes respectively in connexion with two GROVE's elements. At *d* the tube is drawn out to a fine orifice, and at *e* is passed in a current of pure hydrogen prepared as before described, as shown in fig. 10 A. The electric current being passed through the water, to preserve the pure metallic surface of the thallium, heat is applied until the water is entirely volatilized. At this point, and while the tube is very hot, the dry hydrogen still passing, the end of the tube at *d* is sealed up, and then the tube at *h*, previously much contracted, is closed before the blowpipe. The metal is thus enclosed hermetically in an atmosphere of pure hydrogen. The tube and its contents are then cooled for six hours, and when cooled, weighed first in air and then in the vacuum-balance. The tube is now cut across the middle with a cutting diamond, wrapped up in smooth platinum-foil to secure any splinters of glass which might be thrown off, and then broken with a sharp blow opposite the cut. The thallium is carefully removed from the pieces of tube, and introduced into the apparatus where the subsequent operations are to take place. The pieces of tube, with any splinters which may have broken off, are weighed, first in air and then in a highly rarefied atmosphere. The difference between the weighings of the full and empty tube, after correcting for the hydrogen contained at first, gives the weight of thallium taken.

These two forms of apparatus were found to answer the purpose tolerably well. Several improvements, however, suggested themselves whilst the determinations were in progress, and they were finally embodied in the apparatus shown in Plate XVI. figs. 11, 12, & 13. In this several refinements of manipulation can be introduced which were impracticable with the former apparatus—notably the ease with which a definite quantity of metal is introduced into the apparatus without the chance of oxidation, the simplifications introduced in the weighings consequent on having the apparatus vacuous, and the facilities obtained for the employment of the Sprengel and Bunsen pump at different stages of the operations.

Although each determination with this improved apparatus still took many weeks for its successful performance, a great saving of time was effected when compared with that required for a determination in the apparatus first used, where months were consumed in the evaporations. As this form of apparatus was the one in which most of the determinations were effected, and as the manipulations were attended with greater chances of accuracy than were those at first employed, I will describe the apparatus, its employment, and the several processes performed in it somewhat in detail.

Some of the metallic thallium prepared by one of the methods already described is cut by means of a sharp steel knife into prisms about one eighth inch square and half an inch long, no particular care being taken to avoid oxidation. The prisms are boiled in dilute hydrochloric acid to remove any trace of iron which the knife might have communicated. They are then washed in water, dried with blotting-paper, and introduced into the cylindrical portion *a*, fig. 11, of the apparatus. The outer extremity of *a* is then drawn out and sealed before the blowpipe. The end *c* is also sealed up and the horizontal tube *e* is connected to the Sprengel pump and a vacuum obtained, the apparatus and the thallium being kept warm to drive off any moisture which might have been introduced with the thallium. When the vacuum is perfect the tube is sealed at *f*. The apparatus, sealed up and entirely free from air, is now laid on its side, and the cylinder *a* and the bulb *b* imbedded in a bath of magnesia held in a copper vessel heated by gas. The temperature is then raised to above the fusing-point of thallium (561° F.), when by careful manipulation the oxide may be separated from the liquid metal and the greater part of the oxide collected at the closed end of the cylinder *a*. The magnesia is then removed from about the narrow part of the tube *d* (which should be somewhat long and very much contracted), and by a dexterous movement the magnesia-bath containing the apparatus is suddenly tilted up and the liquid metal allowed to run through the contracted part into the bulb *b*. In some instances portions of oxide or of metal stick in the channel, then the operation is lost and a fresh attempt has to be made with another apparatus; but if the channel is entirely or in great part clear, it may be sealed up at the contraction, care being taken to apply the heat at such a place that no particles of metal or oxide are entangled in the fused glass.

The apparatus has now the form shown in fig. 12. It is hermetically sealed, entirely free from air, and contains a certain quantity of pure metallic thallium entirely free from oxide and as brilliant as mercury.

The next operation is to ascertain the combined weight of the apparatus and metal. It is washed on the outside with dilute sulphuric acid to remove any particles of magnesia that might adhere to it, and after rinsing with water is dried and gently warmed. Its weight is then taken in the air-balance—not necessarily with extreme accuracy, but to enable a calculation to be made as to how much it will probably weigh in the vacuum-balance at a greatly reduced atmospheric pressure. As the substance weighed consists of thallium and glass in unknown proportions, the vacuum-weight cannot be calculated with any approach to accuracy; but it is generally easy to arrive at some approximation to the relative proportions of thallium and glass, and in this manner the probable vacuum-weight may be estimated.

The apparatus is now transferred to the vacuum-balance, and weights put which it is judged will balance it at an atmospheric pressure a few barometric inches short of a vacuum. The balance-case is then sealed up, and the exhaustion proceeded with. As the rarefaction proceeds, the beam is occasionally liberated until it is found that the apparatus and weight are in equipoise. If the barometer-gauge shows a rarefaction not equal to 25 inches of mercury, the air had better be let in, the requisite additional weight added, and the exhaustion recommenced; but if, when the balance is in equilibrium, the rarefaction is above 25 inches, the weighing may be continued.

Two sources of error have now to be guarded against:—1. The alteration of temperature inside the iron case consequent on the rarefaction. 2. The slow and almost unavoidable leakage of air into the balance through the iron, the numerous joints, and the stuffing-boxes. This leakage should not exceed 0·1 inch in an hour.

Equilibrium having been obtained, two or three extra strokes are made with the air-pump, and the exhaustion raised to such a point that by about six hours' leakage the balance is again in equipoise. The weights will at first appear lighter than the apparatus. The balance is allowed to remain well protected from external thermal influences, until the time has nearly arrived when the leakage of air into its interior has reduced the rarefaction to the point at which the weights and apparatus will be exactly in equilibrium. The observer now enters the room, and after liberating the beam and setting it in oscillation, watches the movements of the index through a telescope fixed 10 feet off. By reason of the gradual leakage of air the inequality of the oscillations gradually diminishes, until at last the arcs are of the same value. At this moment the temperature inside and outside the balance-case, the height of the barometer-gauge, and the reading of the standard barometer are observed.

Six hours are generally sufficient to restore the temperature reduced by the exhaustion; but if the inner and external thermometers differ, I again rarefy by a few strokes of the pump, and repeat the observation after waiting for a few hours longer.

Having obtained the accurate weight in a rarefied atmosphere, the next step is to weigh the apparatus in air of the ordinary density. Air is allowed slowly to enter the balance through the U-tubes at the side, and in a few hours, when the inner and outer temperatures are uniform, the weight is again taken.

For the final adjustment of the weight the rider may be used. I, however, prefer, as being more accurate, to place a weight slightly in excess in the pan opposite to the apparatus to be weighed, and then, having sealed up the balance, to exhaust a little beyond the point of equilibrium of weight, and continue the operation exactly as in weighing in a rare atmosphere. By taking care that the air contained in the balance shall only be half an inch or so rarer than the external atmosphere, the data afforded by the two weighings will be sufficient to enable the true vacuum-weight of the apparatus to be calculated with accuracy.

This method of ascertaining minute differences of weight, not by the addition to, or subtraction of, material weights from one arm of a balance, but by varying the density of the air in which the operation is performed, is, I believe, attended with a greater approach to accuracy than the method generally adopted. It can, however, only be adopted when the weights and the substance weighed differ in specific gravity.

The data for ascertaining the weight of the apparatus and the thallium it contains have now been obtained. The next operation is to convert the thallium into nitrate. For this purpose, the tube *g* (Plate XVI. fig. 12) must be opened; and to effect this without any risk of losing particles of glass, I gently warm the extremity in a spirit-lamp, and then apply the tip of a blowpipe-flame to the warm glass at *g*. The atmospheric pressure outside acting against the vacuum inside, immediately perforates a small hole through the glass, into which the air rushes.

Some nitric acid, purified in the manner described, is now removed from the bulb in which it has remained sealed up, and a little is introduced into the bulbs *h* and the globe *b*; this is readily effected by alternately warming and cooling *b*, the perforation *g* dipping under the acid. Sufficient nitric acid must be introduced to three quarters fill the two lower bulbs, and also to moisten the thallium in the globe *b*. The apparatus is then placed in a horizontal position, and the quantity of acid in the bulbs is regulated so as to allow air-bubbles to pass in either direction and be washed without spirting acid out.

No reaction, or scarcely any, between strong nitric acid and thallium takes place in the cold; but on applying gentle heat the metal is attacked, and becomes rapidly converted into nitrate. The quantity of acid which is allowed to act at a time must be very limited; and the temperature should not be higher than is sufficient to prevent the nitrate of thallium formed crystallizing on the metal and interfering too much with the action. As soon as the action ceases, a little nitric acid from the washing-bulbs is allowed to run into the globe, its place being supplied with fresh acid. When cold, the crystallization of the nitrate of thallium entirely prevents the reaction between the metal and acid, but on warming, the salt dissolves and the action proceeds. The vapours of nitric and nitrous oxide, which are evolved in abundance, are washed by passing through the system of bulbs, and the reaction must be only just sufficient to cause them to pass through slowly.

In course of time the whole of the thallium is dissolved, and the most tedious part of the process then commences—the evaporation of the excess of free acid.

For this purpose an apparatus is used represented in Plate XVII. *a* is the apparatus connected by a wide tube, *b*, and a narrower glass tube with a bottle, *c*. This is in connexion with a Bunsen's water-pump, *d*, having 18 feet fall of water, and capable of producing an exhaustion equal to 10 inches of mercury. The water is supplied to this pump by an independent pipe and tap attached to a large cistern, so that it can be allowed to work continuously day and night without interfering with the ordinary water-supply of the laboratory. The apparatus *a* is enclosed in a glass case, and stands in an air-bath, the temperature of which can be kept constant by means of a gas-regulator. The water of the pump being set in motion, and a temperature of about 250° F. being maintained in the air-bath, evaporation of the nitric acid commences, the vapour partly condensing in the bottle *c*, and partly being carried away through the pump. As the evaporation of the acid proceeds the temperature is gradually raised, until ultimately it becomes as high as 380° F., which must not be exceeded in this stage of the operation. In course of time (varying from a few days to as many weeks, according to the quantity of acid to be drawn off, and the size of the perforation through which it is to pass) the nitrate of thallium is left in the form of dry white crystals.

The pump is then stopped, and air allowed to enter the apparatus by opening the pinch-cock, *e*, connected with the chloride-of-calcium tubes, *f*. The apparatus being cooled, water is added to the nitrate of thallium in the proportion of bulk for bulk, about 1 grain of oxalic acid* being dissolved in the water. Heat is then applied, and the solution boiled until all the nitrate of thallium is dissolved, forming a clear colourless liquid, which deposits on cooling brilliantly white crystals of nitrate of thallium†.

The nitric acid having been previously removed from the bottle *c* and the rest of the tubes, the apparatus is again fitted to the pump. It is heated in the air-bath, and the water gradually drawn out under diminished pressure, the temperature being kept a little below the point of ebullition of the liquid. When apparently dry the heat is very carefully raised to 394° F., at which temperature the crystals of nitrate of thallium melt; a little froth at first breaks the surface, but this soon disappears, and the liquid becomes as clear and colourless as water. If sufficient oxalic acid has been added to decompose the pernitrate of thallium, no deposit whatever is visible in the liquid; but should any be seen, a fraction of a grain of oxalic acid must be added with the water in the next operation.

---

* If the action of nitric acid on thallium is allowed to become too violent, or if the nitrate of thallium is long heated with excess of nitric acid, a little pernitrate of thallium is formed, which on subsequent fusion of the nitrate deposits a brown powder of peroxide of thallium. The oxalic acid is therefore added to decompose the pernitrate of thallium. The excess of oxalic acid disappears with the last traces of free nitric acid and water.

† Nitrate of thallium is soluble in 9·4 times its weight of water at 60° F., and in less than one fourth of its bulk of boiling water. The crystals deposited on cooling are anhydrous.

As soon as the nitrate is in the form of a clear liquid the apparatus is allowed to cool*, and after being disconnected from the pump is weighed in the air-balance, no particular precautions being taken, however, and the air having free access to the interior of the apparatus.

Water is again added, the nitrate of thallium is dissolved and allowed to crystallize out, and the operation of evaporating the water under diminished pressure in the air-bath is repeated exactly as already described.

The dry nitrate is again fused at 394° F., and after the whole apparatus is heated to about 420° F. for a few minutes it is allowed to cool, and is again weighed. If there has been loss of weight, the operation must be repeated till the weights are constant.

When this is the case the apparatus must be disconnected from the Bunsen water-pump and attached by its extremity *g*, Plate XVI. fig. 12, to the Sprengel mercury-pump. The air is now exhausted as perfectly as possible, and when quite vacuous the tube is sealed up at *i* (fig. 12) by the application of a small spirit-flame. Care must be taken in doing this to lose no particle of glass, as the end of the tube *g* which is drawn off, having been included in the first weighing, must be carefully preserved and weighed along with the apparatus in all the subsequent weighings.

The apparatus is now of the form shown in fig. 13. It contains nothing but the pure nitrate of thallium produced from the action of nitric acid on the thallium at first introduced, and is entirely free from air. It is now, with the loose piece of tube *g* belonging to it, to be weighed in the vacuum-balance at two different atmospheric pressures, with all the precautions already adopted in the previous weighings.

When the data for ascertaining the weight of the glass apparatus and the nitrate of thallium are correctly obtained, the weight of the glass apparatus by itself has to be taken. For this purpose a hole is perforated in the tube *i*, as before described, by means of a blowpipe-flame, and water being introduced the nitrate of thallium is dissolved out, and by repeated washings ultimately removed. The completion of the operation is ascertained by evaporating some of the washing water almost to dryness, and testing by means of the spectroscope. The apparatus is then dried, connected with the Sprengel pump, and after complete exhaustion it is sealed up at *h*, the same precautions being taken to preserve the piece of tube now removed as were adopted in the previous sealing up.

The empty apparatus is now to be weighed at different atmospheric pressures in the vacuum-balance with all necessary precautions, the two loose pieces of glass tube *g* and

---

* If a considerable bulk of fused nitrate of thallium is allowed to solidify in a thin bulb, the glass is almost certain to crack, owing to unequal contraction. Many of my operations were spoilt by this cause. By keeping the apparatus in motion during solidification, so as to allow the nitrate to line the greater part of the inner surface of the bulb, this source of danger is avoided.

i h being now included, and from the data thus obtained its true weight is calculated. There have thus been obtained:—

α. The weight of the glass+thallium.

β. The weight of the glass+nitrate of thallium.

γ. The weight of the glass alone.

From these data the atomic weight of thallium can be calculated by the formulæ given in the next section.

SECTION V.—CALCULATION OF THE RESULTS.

The succeeding results must not be regarded as embodying all the attempts to determine the atomic weight; for, as stated in the preceding section, many of the apparatus were broken at various stages of the operation. The calculations, however, serve to illustrate the weighings which came to a successful issue.

For the accurate determination of the weighings, it will be seen that it is necessary to ascertain the density of the ordinary atmosphere at the place where the weighings are made. RITTER has deduced from REGNAULT'S observations that in Paris, lat. 48° 50′ 14″, at 60 metres above the level of the sea, a litre of dry atmospheric air at 0° C. and 760 millims. pressure weighs 1·2932227 gramme. It is well established that if G represents the force of gravity at the mean level of the sea in lat. 45°, the force of gravity in lat. λ at the mean level of the sea$=G(1-0{\cdot}0025659\cos 2\lambda)$.

The force of gravity in a given latitude at a place on the surface of the earth at a height z above the mean level of the sea

$$=\left\{1-\left(2-\frac{3}{2}\frac{\varsigma'}{\varsigma}\right)\frac{z}{r}\right\}$$

multiplied by the force of gravity at the level of the sea in the same latitude, r being the radius of the earth$=63966198$ metres, ς its mean density, and ς' the density of that part of the earth which is above the mean level of the sea; and if the ratio $\varsigma':\varsigma$ be taken as 5 : 11, then

$$2-\frac{3}{2}\frac{\varsigma'}{\varsigma}=1{\cdot}32 \text{ nearly.}$$

Continuing the reasoning, Professor MILLER has shown that a litre of dry atmospheric air, containing the average amount of carbonic acid, at 0° and 760 millims. pressure, at the height z above the mean level of the sea in lat. λ, weighs in grammes

$$1{\cdot}2930693\left(1-1{\cdot}32\frac{z}{r}\right)(1-0{\cdot}0025659\cos 2\lambda).$$

It has been shown by REGNAULT and others that, between 0° and 50°, the ratio of the density of air at 0° to its density at $t°$ is $1+0{\cdot}003656t$, and that the density of the vapour of water is 0·622 of that of air. Therefore the weight in grammes of a litre of air will be

$$\frac{1{\cdot}2930693}{1+0{\cdot}003656t}\;\frac{b-0{\cdot}378v}{760}\left(1-1{\cdot}32\frac{z}{r}\right)(1-0{\cdot}0025659\cos 2\lambda),$$

where t is the temperature of the air, b the barometric pressure, v the pressure of the vapour (of water) present in the air, both expressed in millimetres of mercury at 0°, z the height above the mean level of the sea, λ the latitude. My laboratory at Mornington Road, Regent's Park, where the atomic weight of thallium was determined, is in lat. 51° 32′ 6″, at a height of 35·05 metres above the mean level of the sea. The expression consequently becomes

$$\frac{1{\cdot}2930693}{1+0{\cdot}003656t} \cdot \frac{b-0{\cdot}378v}{760} \,(\cdot 99999289815)\,(1{\cdot}0005802549).$$

As a litre is the volume of 1000 grammes of water at its maximum density, the division of this expression by 1000 gives the ratio of the density of air to the maximum density of water. By the addition of the logarithm of $b-0{\cdot}378v$ in millimetres to $\log A_t$ we obtain the logarithm of the ratio of the density of air at $t°$ to the maximum density of water.

TABLE A.—Calculated for Mornington Road, Regent's Park.

t.	$10+\log A_t$.	Diff.
0	4·231055	
		1585
1	4·229470	
		1579
2	4·227890	
		1574
3	4·226317	
		1567
4	4·224750	
		1563
5	4·223187	
		1556
6	4·221631	
		1551
7	4·220980	
		1545
8	4·218535	
		1540
9	4·216995	
		1535
10	4·215460	
		1529
11	4·213931	
		1524
12	4·212407	
		1518
13	4·210889	
		1513
14	4·209376	
		1508
15	4·207868	
15	4·207868	
		1502
16	4·206366	
		1498
17	4·204868	
		1492
18	4·203376	
		1487
19	4·201889	
		1483
20	4·200406	
		1477
21	4·198925	
		1471
22	4·197458	
		1468
23	4·195990	
		1462
24	4·194528	
		1457
25	4·193071	
		1452
26	4·191618	
		1447
27	4·190171	
		1443
28	4·188728	
		1438
29	4·187290	
		1433
30	4·185857	

These logarithms, when increased by 0·000030, agree with those employed by Professor MILLER in his determination of the value of the new standard pound (see Phil. Trans. for 1856) when working in the cellar under the Mineralogical Museum at Cambridge, in lat. 52° 12′ 18″, about 8 metres above the mean level of the sea; increased by 0·000002 they can be used in reducing weighings in Somerset House, lat. 51° 30′ 40″, 29·56 metres above sea-level; or diminished by 0·000102 for weighings made in Paris.

We have next to consider the influence exerted by the hygrometric state of the atmosphere, or, in other words, the influence of the vapour of water suspended in the atmosphere. It is clear that the moist air is nothing more than a mixture of v cubic inches of dry air at $t°$ under a pressure minus that of the vapour, and of v cubic inches of vapour at $t°$ and the pressure resulting from the hygrometric condition. BIOT, REGNAULT, and BIANCHI have ascertained that the pressure of vapour in an ordinary dry room is two thirds of the maximum pressure due to the temperature.

TABLE B.—Values of $0·378\times\frac{2}{3}v_t$, where v_t is the maximum pressure of vapour at the temperature t, in millims. of mercury at 0°, according to REGNAULT'S observations*.

t.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0	1·16	1·17	1·18	1·18	1·19	1·20	1·21	1·22	1·23	1·24
1	1·25	1·25	1·26	1·27	1·28	1·29	1·30	1·31	1·32	1·33
2	1·34	1·35	1·36	1·37	1·37	1·38	1·39	1·40	1·41	1·42
3	1·43	1·44	1·45	1·46	1·47	1·48	1·49	1·50	1·51	1·53
4	1·54	1·55	1·56	1·57	1·58	1·59	1·60	1·61	1·63	1·64
5	1·65	1·66	1·67	1·68	1·69	1·70	1·72	1·73	1·74	1·75
6	1·76	1·78	1·79	1·80	1·81	1·82	1·84	1·85	1·86	1·87
7	1·89	1·90	1·91	1·93	1·94	1·95	1·96	1·98	1·99	2·01
8	2·02	2·03	2·05	2·06	2·08	2·09	2·10	2·12	2·13	2·15
9	2·16	2·17	2·19	2·21	2·22	2·24	2·25	2·27	2·28	2·29
10	2·31	2·32	2·34	2·35	2·37	2·39	2·40	2·42	2·44	2·45
11	2·47	2·48	2·50	2·52	2·53	2·55	2·57	2·58	2·60	2·62
12	2·64	2·65	2·67	2·69	2·71	2·72	2·74	2·76	2·78	2·80
13	2·81	2·83	2·85	2·87	2·89	2·91	2·93	2·94	2·96	2·98
14	3·00	3·02	3·04	3·06	3·08	3·10	3·12	3·14	3·16	3·18
15	3·20	3·22	3·24	3·26	3·28	3·31	3·33	3·35	3·37	3·39
16	3·41	3·43	3·46	3·48	3·50	3·52	3·54	3·57	3·59	3·61
17	3·63	3·66	3·68	3·71	3·73	3·75	3·78	3·80	3·82	3·85
18	3·87	3·90	3·92	3·95	3·97	4·00	4·02	4·04	4·07	4·09
19	4·12	4·15	4·17	4·20	4·22	4·25	4·28	4·30	4·33	4·36
20	4·38	4·41	4·44	4·47	4·49	4·52	4·55	4·58	4·61	4·63
21	4·66	4·69	4·72	4·75	4·78	4·81	4·84	4·87	4·90	4·92
22	4·95	4·99	5·02	5·05	5·08	5·11	5·14	5·17	5·20	5·23
23	5·26	5·30	5·33	5·36	5·39	5·43	5·46	5·49	5·52	5·56
24	5·59	5·62	5·66	5·69	5·73	5·76	5·80	5·83	5·87	5·90
25	5·93	5·97	6·01	6·04	6·08	6·12	6·15	6·19	6·22	6·26
26	6·30	6·34	6·37	6·41	6·45	6·49	6·53	6·56	6·60	6·64
27	6·68	6·72	6·75	6·79	6·83	6·87	6·91	6·95	6·99	7·03
28	7·08	7·12	9·17	7·21	7·25	7·29	7·34	7·38	7·42	7·46
29	7·51	7·55	7·59	7·64	7·68	7·73	7·77	7·82	7·86	7·91
30	7·95	8·00	8·04	8·09	8·14	8·18	8·23	8 28	8·23	8·37

The formula employed for the calculation of the true weight of a substance *in vacuo*, from data given by two weighings, one at ordinary and one at a greatly diminished air-pressure, is as follows:—

---

* Annales de Chimie, 1845, 3^me^ série, tome xv. p. 138.

Let H denote the substance to be weighed, and
h its true weight (*in vacuo*) in grains.

First Weighing in Air of Ordinary Density.

Let W denote the material weight which balances H,
w ,, ,, true weight of W observed in air,
x ,, ,, weight of air displaced by W,
t ,, ,, temperature,
p ,, ,, pressure, in height of mercury, reduced to 32° F.,
b ,, ,, bulk of W in grs. of water at max. density,
k ,, ,, weight of air displaced by H:

w, x, t, p, b being given, required to find k,

$$h-k=w-x.$$

Second Weighing in a Rare Atmosphere.

Let γ denote the weights which balance H,
y ,, ,, true weight of γ in air of ordinary density,
z ,, ,, weight of air displaced by γ,
t' ,, ,, temperature,
p' ,, ,, pressure, in height of mercury, reduced to 32° F.,
$b'=\frac{y}{w}b$,, bulk of γ in grains of water at max. density,
l denote the weight of air displaced by H:

y, t', p', b' being given, to find l and z,

$$h-l=y-z;$$

hence $k-l=y-w+x-z$.

By Tables A and B,

$$\log\frac{\text{density rare air}}{\text{max. den. water}}=\log(p'-0{\cdot}378\tfrac{2}{3}\,v_t)+\log\frac{0{\cdot}001293893}{1+0{\cdot}003656}\cdot\frac{1}{760};$$

$$\therefore \log\ b'+\log\frac{\text{density rare air}}{\text{max. density water}}=\log z,$$

$$\frac{l}{k}=\frac{\text{density rare air}}{\text{density common air}}=n \text{ (suppose).}$$

Let $m=y-w+x-z$; then $k-l=m$, $\frac{l}{k}=n$.

Hence $l=nk$, $k-nk=m$, $k=\frac{m}{1-n}$, $l=\frac{mn}{1-n}$.

Hence $h=w-x+\frac{m}{1-n}$; or $h=y-z+\frac{mn}{1-n}$.

To illustrate the application of this formula, I will reduce the weighings of one of the determinations (E).

Substance weighed.	Balance used.	Weights, actual.	True value in air.
(H)		(W)	(w)
Glass apparatus.	Vac.	765·8081	765·814578
(H)		(γ)	(y)
Glass apparatus.	Vac.	766·1133	766·122626

Weight of air displaced.	Temperature.	Bar. (reduced to 32° F.).
(x)	(t)	(p)
0·044547	65° F.=18°·5 C.	29·848
(vol. in water max. density=36·326)		(758·125 millims.)
	(t')	(p')
0·044546	63° F.=17° C.	1·173 in.
		(29·79 millims.)

CALCULATION OF VACUUM-WEIGHT OF FLASK FROM ABOVE WEIGHINGS.

Let h=true weight in vacuum of flask,

$w=765\cdot814578$,

$x=0\cdot044547$,

$t=65°$ F.$=18°\cdot33$ C.,

$p=29\cdot848$ in.$=758\cdot12$ millims.,

$b=36\cdot326$,

$y=766\cdot122626$,

$t'=63°$ F.$=17°\cdot2$ C.,

$p'=1\cdot173$ in.$=29\cdot79$ millims.

$$\log\frac{\text{density atmospheric air}}{\text{max. density water}}=\log 758\cdot12-4\cdot00+4\cdot204149-10;$$

$$\therefore \quad ,, \quad = 2\cdot8774430+4\cdot204149-10;$$

$$\therefore \quad ,, \quad = 7\cdot0815920-10.$$

$$\log b'=\log 766\cdot122626-\log 765\cdot814578+\log 36\cdot326;$$

$$\therefore \ b'=2\cdot8842970-2\cdot8841230+1\cdot5602176;$$

$$\therefore \ b'=1\cdot5603916.$$

$$\log\frac{\text{density rare air}}{\text{max. den. water}}=\log(29\cdot79-3\cdot63)+4\cdot204898-10;$$

$$\therefore \quad ,, \quad = 1\cdot4176377+4\cdot204898-10;$$

$$\therefore \quad ,, \quad = 5\cdot6225357-10.$$

$\log z = 1{\cdot}5603916 + 5{\cdot}6225357 - 10;$

$\therefore\ z = 7{\cdot}1829373 - 10;$

$\therefore\ z = 0{\cdot}001524.$

$\log \frac{l}{k} = 5{\cdot}6225357 - 7{\cdot}0815920;$

$\therefore\ \frac{l}{k} = 8{\cdot}5409437 - 10;$

$\therefore\ n = \frac{l}{k} = 0{\cdot}034749;$

$\therefore\ 1 - n = 0{\cdot}965251.$

$m = 766{\cdot}122626 - 765{\cdot}814578 + 0{\cdot}044547 - 0{\cdot}001524;$

$\therefore\ m = 0{\cdot}351071.$

$k = \frac{m}{1-n} = \frac{0{\cdot}351071}{0{\cdot}965251};$

$\therefore\ k = 0{\cdot}3638.$

$h = 765{\cdot}814578 - 0{\cdot}044547 + {\cdot}3638;$

$\therefore\ h = 766{\cdot}133831.$

WEIGHING OF GLASS APPARATUS + NITRATE OF THALLIUM.

Vacuum-balance.

In air. Left pan removed. Platinum weights.

After third heating (to fusion) and cooling:—

Weights.	True value in air.	Weight of air displaced.	Volume in water at max. density.
600	599·998340	0·035533	28·970
100	99·991420	5887	4·800
60	59·993232	3483	2·840
30	29·999991	1668	1·360
6	5·998268	355	·290
3	3·000469	171	·140
·06	0·061472	3	·003
·0031	0·003099	0	·000
799·0631	799·046291	0·047100	38·403
Pan=206·3733	206·379646	0·012040	9·824
1005·4364	1005·425937	0·059140	48·227

Therm.=73° F.=22°·7 C.

Barom.=29·891 in. at 0° C.=759·22 millims.

1005·425937

765·814578=weight of glass apparatus (see *w*, preceding).

239·611359=weight of thallium nitrate in air.

The weight of air displaced &c. is taken separately for each weight in all cases, but is omitted in subsequent examples (the sum being given), to prevent the introduction of useless figures.

WEIGHING OF GLASS APPARATUS + NITRATE OF THALLIUM IN RARE ATMOSPHERE.

Vacum-balance.

Exhausted. Left pan removed. Platinum weights.

	Weights.	True value in air.	Weight of air displaced.	Volume in water at max. density.
	799·3600	799·346792	0·047117	38·423
Pan =	206·3733	206·379646	0·012040	9·824
	1005·7333	1005·726438	0·059157	48·247

Therm. = 69°·5 F. = 21° C.
Barom. = 29·775 in. = 756·27 millims. at 0° C.
Gauge = 25·141 in. = 638·57 millims. at 0° C.

$$\begin{array}{r} 756{\cdot}27 \\ 638{\cdot}57 \\ \hline 117{\cdot}70 \end{array}$$ millims. pressure.

Weight of left scale-pan of air-balance, which was removed to relieve the beam in weighing the heavier pieces of apparatus:—

Weight.	True value in air.	Weight of air displaced.	Volume in water at max. density.
179·7365	179·719377	0·010429	8·513

Weight of left scale-pan of vacuum-balance taken in air-balance:—

Weight.	True value in air.	Weight of air displaced.	Volume in water at max. density.
206·3733	206·3719646	0·012040	9·824

Weight of air displaced by scale-pan = 0·02403 gr.
Volume in water of maximum density = 24·244 grs.

CALCULATION OF VACUUM-WEIGHT OF GLASS APPARATUS + NITRATE OF THALLIUM FROM GIVEN DATA.

First Weighing in Air of Ordinary Density.

By Table A,

$$\log \frac{0{\cdot}00129381}{1+0{\cdot}03656t} \cdot \frac{1}{780} \text{ for } 22^{\circ}{\cdot}7 \text{ C.}$$

$$\begin{array}{lll} t\,22^{\circ} & \text{is} & 4{\cdot}197488-10 \\ t\,{\cdot}7 & \text{is} & \underline{\quad\quad 1027\quad\quad} \\ & & 4{\cdot}198515-10 \end{array}$$

By Table B,

$$0{\cdot}378\tfrac{2}{3}\,v \text{ for } t=22{\cdot}7=5{\cdot}17 \text{ millims.}$$

$$759{\cdot}22-5{\cdot}17=753{\cdot}05;$$

$$\log(753{\cdot}05)=(2{\cdot}8768238-10)+4{\cdot}198515=$$

$$\log 7{\cdot}0753388-10=\log\frac{\text{dens. atmos. air}}{\text{max. dens. water}}.$$

Second Weighing in a Rare Atmosphere.

By Table A the value of

$$\log\frac{0{\cdot}0012938}{1+0{\cdot}00365t}\cdot\frac{1}{768} \text{ for } t=21^\circ \text{ C.}=(4{\cdot}198959-10)+2{\cdot}0532321=6{\cdot}2521911-10=$$

$$\log\frac{\text{dens. rare air}}{\text{max. dens. water}}.$$

Value of $0{\cdot}378\tfrac{2}{3}\,v$ for $t=21^\circ$ C.$=4{\cdot}66$ millims.:

$$117{\cdot}70 \text{ millims. (pressure)}-4{\cdot}66=113{\cdot}04=p'-0{\cdot}378\tfrac{2}{3}\,v,$$

$$\log b'=1{\cdot}6834703+6{\cdot}2521911-10=7{\cdot}9356614-10;$$

$$\therefore\ {\cdot}0086231=z=\text{weight of rare air displaced by } \gamma.$$

The data now are,—

$$w=1005{\cdot}425937,$$

$$x=\quad 0{\cdot}059140,$$

$$y=1005{\cdot}726438,$$

$$z=\quad 0{\cdot}0086231,$$

$$\log\frac{l}{k}=6{\cdot}2521911-7{\cdot}07653388=9{\cdot}1768523-10.$$

Hence $n=\frac{l}{k}={\cdot}15026$:

$$1-n={\cdot}84974,$$

$$y-w=1005{\cdot}726438-1005{\cdot}425937={\cdot}300501,$$

$$x-z={\cdot}059140-{\cdot}008623+={\cdot}050517;$$

$$\therefore\ m-y-w+x-z={\cdot}351018.$$

$$k=\frac{m}{1-n}=\log{\cdot}351018-\log{\cdot}84974={\cdot}5453418-{\cdot}9292861={\cdot}6160557=k={\cdot}4131,$$

$$w-x=1005{\cdot}425937-{\cdot}059140=1005{\cdot}366797.$$

$(w-x)-k=1005{\cdot}366797-{\cdot}4131=1005{\cdot}779897=h$ = true weight of glass apparatus plus nitrate of thallium *in vacuo*.

$1005{\cdot}779897-766{\cdot}133831$ (weight of glass apparatus *in vacuo*)$=239{\cdot}646066=$ weight of nitrate of thallium *in vacuo*.

$239{\cdot}646066-239{\cdot}611359$ (weight of nitrate of thallium in air) $={\cdot}034707=$ increase in weight for vacuum.

WEIGHT OF THALLIUM*.

Weight of thallium taken	=	183·783921
Air displaced by thallium	=	0·018907
		183·802828
Deduct air displaced by weights . . .	=	0·012596
True weight of thallium *in vacuo* . . .		183·790232

Collecting the data, we have

† True weight of thallium *in vacuo*	=183·790232	grs.
,, ,, nitrate of thallium *in vacuo* . .	=239·646066	,,
,, ,, glass *in vacuo*	=766·133831	,,

The reduction of the atomic weight from data obtained in the manner of the preceding weighings becomes a case of simple proportion; but the values found are absolute in so far only as the atomic weights of nitrogen and oxygen are correct. The atomic weights of nitrogen and oxygen have been usually represented by the numbers 14 and 16; but Professor STAS found these elements represented, according to observation, by 14·009 and 15·960. Therefore, oxygen $(O_3)=47·880$, and nitrogen $=14·009$, or $NO_3=61·889$. According to the old equivalents, $NO_6=62$.

Taking as data the series of weighings *in vacuo*, the quantity of NO_3 required to convert the thallium into nitrate is

$$(239·646066-183·790232=)55·855834 \text{ grms.}$$

We have, then, with Professor STAS's determination of the atomic weights of nitrogen and oxygen, the following proportion:—

Weight of NO_3.		Weight of thallium.		Atomic weight of NO_3.		Atomic weight of thallium.
55·855834	:	183·790232	::	61·889	:	x;

$$\therefore \quad x=203·642.$$

This number, it will presently appear, represents the atomic weight of thallium as nearly as the possibility of error will allow.

Let us see what would be the atomic weight of thallium if one or other of the corrections introduced into the above determination had been omitted. The use of the old equivalent (=62) for NO_6, with the data derived from the weighings *in vacuo*, gives

$$55·855834 \quad : \quad 183·790232 \quad :: \quad 62 \quad : \quad 204·007$$

as the atomic weight; but I cannot admit this number to be so correct as 203·642.

If we take the corrected weighings in air of ordinary density, we have with $NO_3=61·889$,

$$55·827438 \quad : \quad 183·783921 \quad :: \quad 61·889 \quad : \quad 203·738.$$

---

* To save needless repetition, I only give the results of these calculations.

† In this determination the thallium and afterwards the nitrate of thallium were weighed in the same glass apparatus as described.

With $NO_6=62$,

55·827438 : 183·783921 :: 62 : 204·103.

Accepting the uncorrected weights observed in air, we have, with $NO_3=61·889$,

55·8184 : 183·8099 :: 61·889 : 203·800.

With $NO_6=62$,

55·8184 : 183·8099 :: 62 : 204·166.

The several atomic weights would therefore be

203·642	204·007
203·738	204·103
203·800	204·166

The error of the last deduction, +·524, is sufficiently large to show the necessity of neglecting no precaution in chemical manipulation, especially in a determination of this character. The largeness of these errors has an immediate bearing upon quantitative analysis; for it shows that from data ordinarily given, very varying results may be obtained. Chemists have to deal with much smaller quantities than a quarter per cent., particularly in organic analysis, where, as I have shown, such a difference from the truth may lead to very erroneous reasoning.

RESULTS.

Ten results of the most trustworthy weighings (with $NO_3=61·889$) are*:—

	True Weights *in vacuo.*			
Determination.	Weight of thallium taken. grs.	Weight of nitrate of thallium + glass. grs.	Weight of glass. grs.	Calculated atomic weight from these data. grs.
A.	497·972995	1121·851852	472·557319	203·666
B.	293·193507	1111·387014	729·082713	203·628
C.	288·562777	971·214142	594·949719	203·632
D.	324·963740	1142·569408	718·849078	203·649
†E.	183·790232	1005·366796	766·133831	203·642
F.	190·842532	997·334615	748·491271	203·636
G.	195·544324	1022·176679	767·203451	203·639
H.	201·856345	1013·480135	750·332401	203·650
I.	295·683523	1153·947672	768·403621	203·644
K.	299·203036	1159·870052	769·734201	203·638

---

* It should be noted that the arithmetic mean of *all* the readings, including the highest as well as the lowest result, in which doubt might arise as to success in manipulation, is 203·6.

† Fully illustrated in the preceding text.

I wish it to be noted that I have made determinations with considerable weights of thallium. In ordinary analysis chemists are satisfied to take 5 or 10 grains of the substance under investigation: here I have gone to the very highest weight that can be entrusted, with safety, to the balance. The lowest weight of thallium taken is 183·790232 grains, the heaviest 497·972995 grains, the remaining determinations varying between these limits. It is hardly necessary to say that the purpose has been to eliminate the error arising from manipulation with small quantities, and to produce such variety in the results as to render the chances of coincidence of very small value.

Let me now tabulate the results of the determination, with the view to ascertain severally their degree of approximation to the arithmetic mean:—

A.	203·666	+·024
B.	203·628	—·014
C.	203·632	—·010
D.	203·649	+·007
E.	203·642	·000
F.	203·636	—·006
G.	203·639	—·003
H.	203·650	+·008
I.	203·644	+·002
K.	203·638	—·004

The arithmetic mean of the ten observations is

$$\alpha=\frac{2036·424}{10}=203·642.$$

But does this average represent the truth? Or, rather, how nearly does it represent the truth?

According to the theory of probabilities, the "weight" of α may be determined by means of the formula

$$w=\frac{n^2}{2\Sigma e^2},$$

where $n=$ the number of observations, and $\Sigma e^2=$ the sum of the squares of the successive differences, obtained by subtracting *each* observation from the arithmetic mean of the *whole.*

The arithmetic mean of the ten weighings is $\alpha=203·642$.

The sum of the squares of the ten differences between α and each individual observation is:—

e.	e^2.
+·024	·000576
+·008	·000064
+·007	·000049
+·002	·000004
·000	·000000
−·003	·000009
−·004	·000016
−·006	·000036
−·010	·000100
−·014	·000196
	Σe^2=·001050

Hence the "weight" of α is

$$w=\frac{(\text{number of observations})^2}{2\Sigma e^2}$$

$$=\frac{100}{\cdot 0021}$$

$$=47619.$$

The largeness of this figure indicates the high degree of probability that α is very near to the true value sought. But the question, What is the true value? does not admit of absolute answer; for one of the observations was as low as 203·628, and one as high as 203·666. The number of possible values between 203·628 and 203·666 is infinite, the arithmetic mean α being but one of these values; and although more likely than any other that could be *named*, it is not more likely than *one or other* of all the possible values. The odds are many to one that α is *not* the truth; but they are also many to one that α is very near the truth. The question "How near?" cannot be answered; alter the question to "What is the probability that the truth is comprised within the limits $\alpha \pm k$?" and the answer may be easily given, *however small k may be.* Thus if k=·01,—in other words, if the question be "What is the degree of likelihood that the truth lies between 203·632 and 203·652?"—the answer is given by the formulæ

$$\left.\begin{array}{l}\pi=\mathrm{H},\\ t=k\sqrt{w},\end{array}\right\}$$

having recourse to tables calculated from the celebrated Definite Integral,

$$\mathrm{H}_t=\frac{2}{\sqrt{\pi}}\cdot\int_0^t e^{-t}\,.\,dx.$$

Let

$$k = \cdot 01,$$
$$w = 47619,$$
$$\sqrt{w} = 218,$$
$$\therefore \quad t = k\sqrt{w} = 2\cdot 18,$$
$$\therefore \quad \pi = H_{2\cdot 17} = \cdot 99795.$$

(See Table I., at end of Professor De Morgan's 'Essay on Probabilities'.)

The result, $= \cdot 99795$, is so near to unity, the measure of *certainty*, that for every practical purpose it may be considered *certain* that the truth is really comprised within the limits named.

By Table II. in Professor De Morgan's Essay, we can test the correctness of the preceding deductions; for

$$\frac{62}{130\sqrt{w}} = \text{the probable error},$$

$$\frac{k}{\text{probable error}} = t.$$

Then K, answering to t in Table II., is the probability required.

Hence

$$\text{where} \quad w = 47619,$$
$$,, \quad \sqrt{w} = 218,$$
$$\frac{62}{130\sqrt{w}} = \cdot 0022,$$
$$\frac{k}{\cdot 0022} = \frac{\cdot 01}{\cdot 0022} = 4\cdot 6 = t,$$

to which corresponds in Table II. K=99808, against 99795, as before.

I may therefore conclude that, within the limits of error (as small as possible) of observation, the

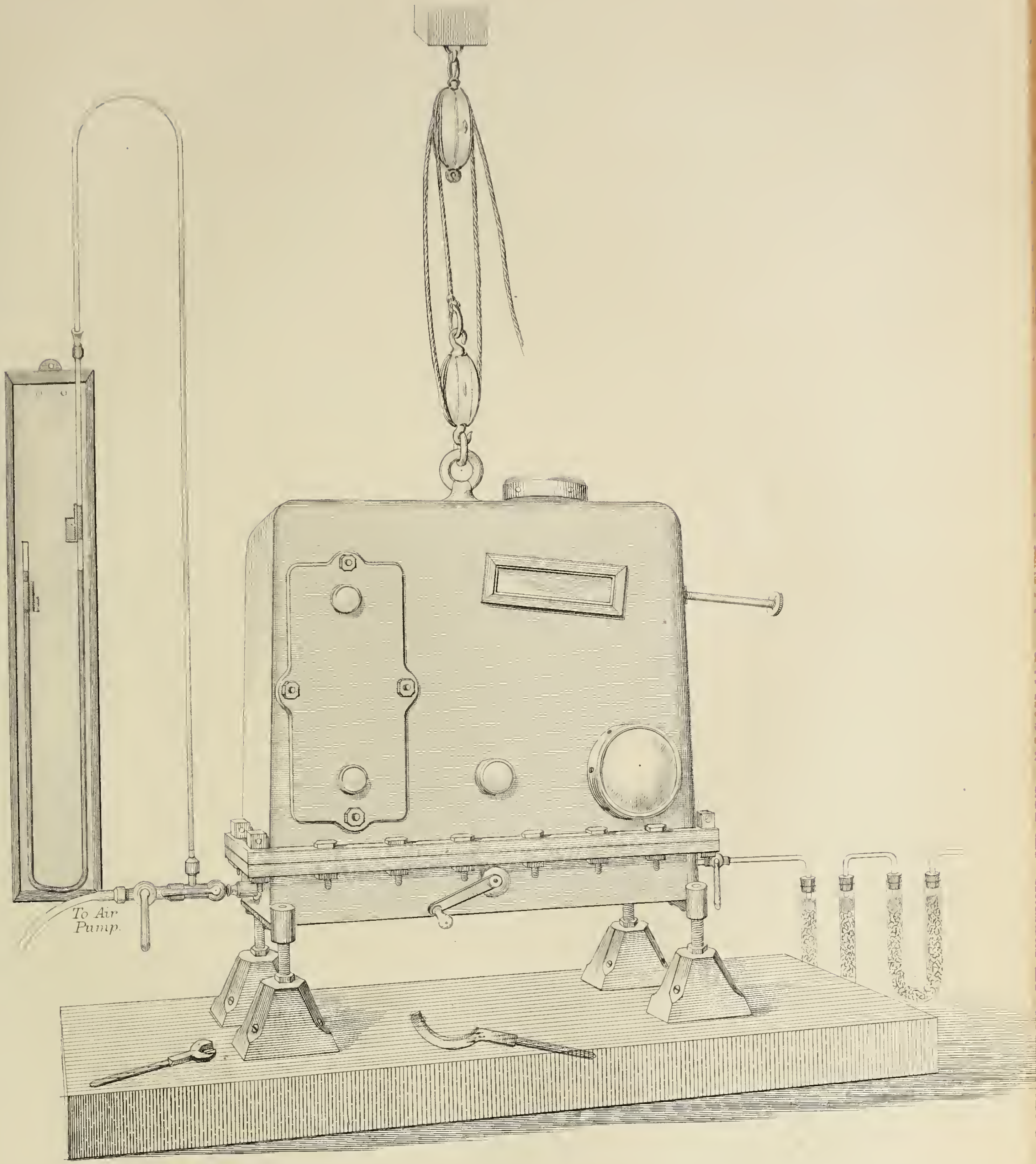
ATOMIC WEIGHT OF THALLIUM=203·642.

Professor Stas has shown the hypothesis of Prout—that the atomic weights of the elements are severally multiples of the atomic weight of hydrogen—to be without the corroboration of experimental result. This view of the hypothesis is further borne out in the present investigation; for the number 203·642 cannot, within the limit of what has been shown to be the probable error, by any liberty be made to follow the hypothesis. Without doubt, when the atomic weights of all the metals are redetermined according to the standard of recent scientific method, it will be found that there are more exceptions to the hypothesis than are commonly considered. Marignac gives, in his confirmatory discussion of Stas's experiments and in his own results with calcium

(40·21), lanthanum (94·13), strontium (87·25), analogous opposed evidence, as in the case of the weight found for thallium.

In the preceding pages I have given the method by which I have arrived at the atomic weight of thallium, whilst I have endeavoured to show that experimental chemistry is strictly a science of precision. Accordingly the determination of the atomic weights of other of the elements (gold, chromium, platinum, rhodium, ruthenium, palladium, iridium, lithium, glucinum, cerium, and boron) is not a matter of supererogatory labour undertaken for the sake of verification merely, but is necessary to the progress of chemistry immediately as a science and technologically. For, until these elements shall have assigned to them more accurately their combining numbers, it will not be safe to enter into theoretical speculations respecting the interrelations between elementary bodies, nor possible to estimate them quantitatively without some error, which, small as it may be, yet remains an inaccuracy inadmissible to true science. One of the sources of error (that of neglecting the variation of atmospheric pressure during the weighings), it will have been seen, frequently introduces as much defect from the truth as impurity of the chemicals employed—a fact that has hitherto been greatly overlooked. Undoubtedly larger errors are sometimes admitted to general chemical manipulation from deficiency or excess in the weights employed than would obtain from the use of materials of ordinary purity, although in the latter case to notice effects of variable pressure, or the loss by weight of air displaced, would be labour wasted.

Bearing these teachings of experience in my mind, I have striven to eliminate all erroneous influence in the number I submit to the Royal Society as the Atomic Weight of Thallium; and I shall be amply rewarded for my long labour if I can know that the determination has secured to researches of this character a nearer approach to the standard of truth.

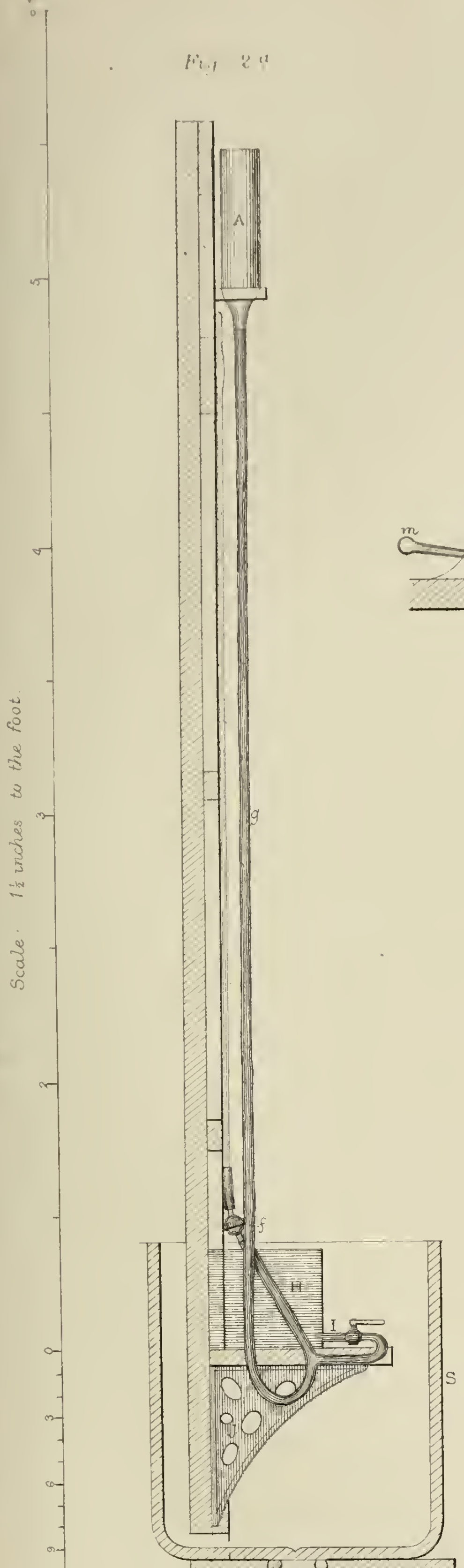


W H Wes

[illegible] imp

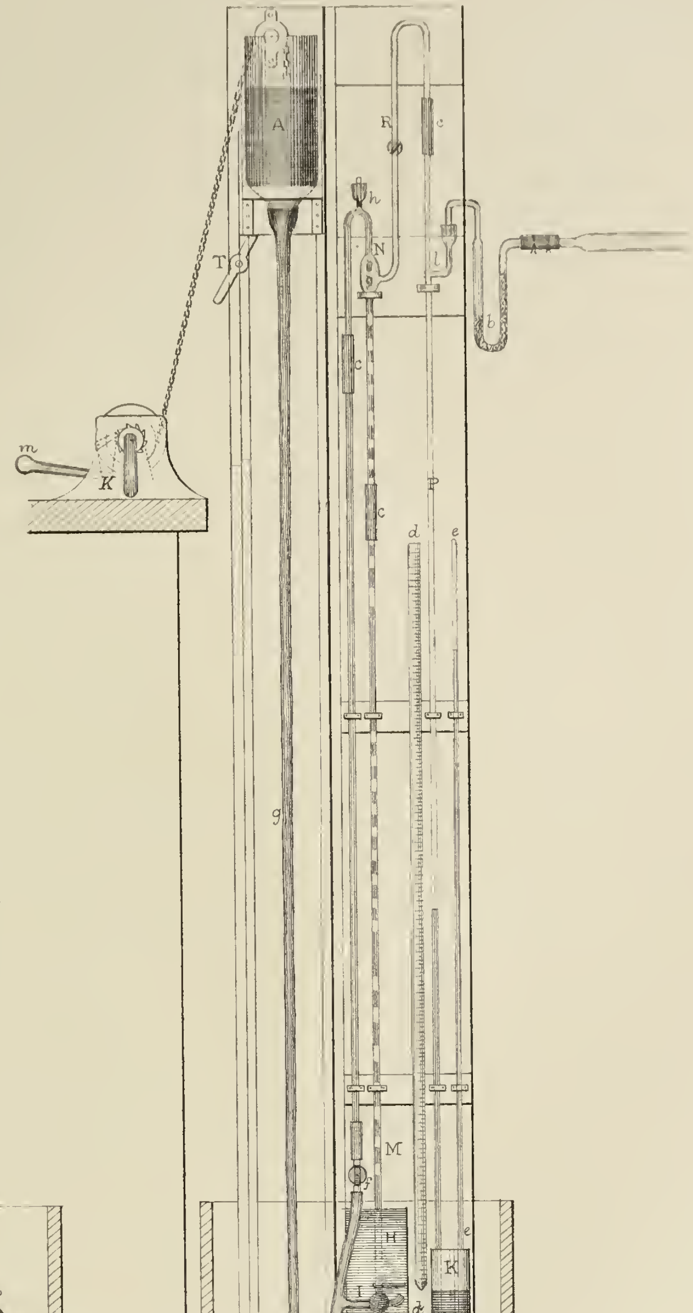
LIBRARY
OF THE
UNIVERSITY of ILLINOIS

Fig 2a



Scale: 1½ inches to the foot.

Fig 2



W. H. Wesley lith.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

Fig 1.

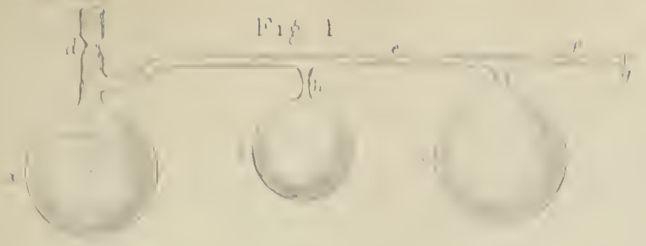


Fig 2.

Fig 3.

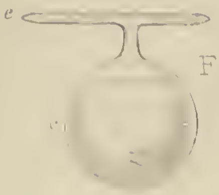


Fig 4.

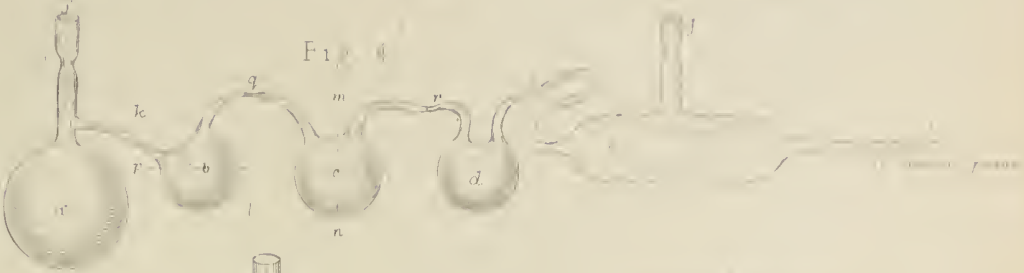


Fig 4 a

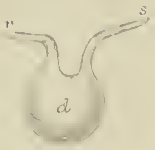
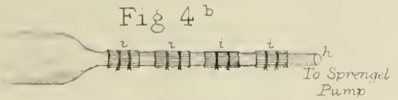


Fig 4 b



Flexible Joint

Fig 5.

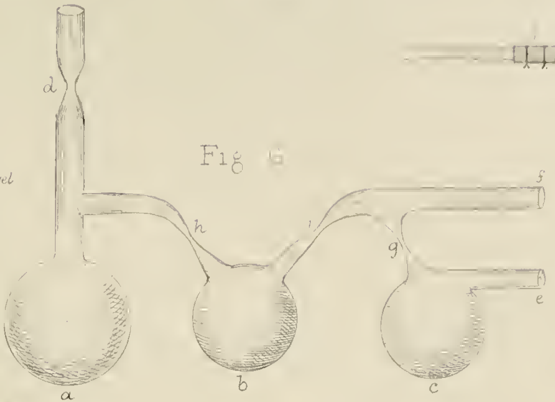


Fig 6.

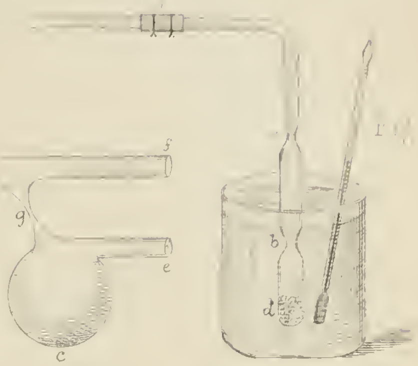


Fig. 7.

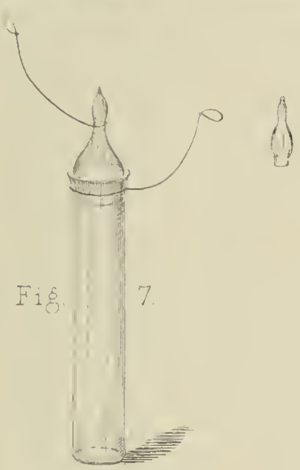


Fig. 8.

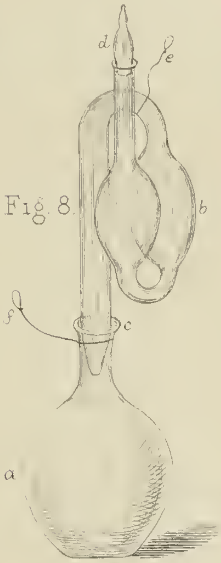


Fig. 10 A

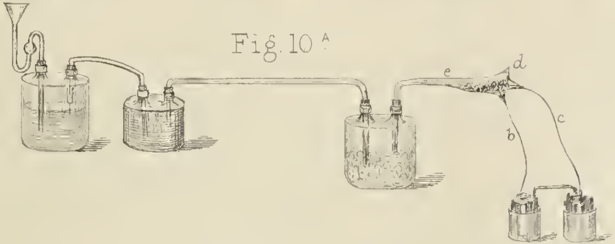


Fig 10.

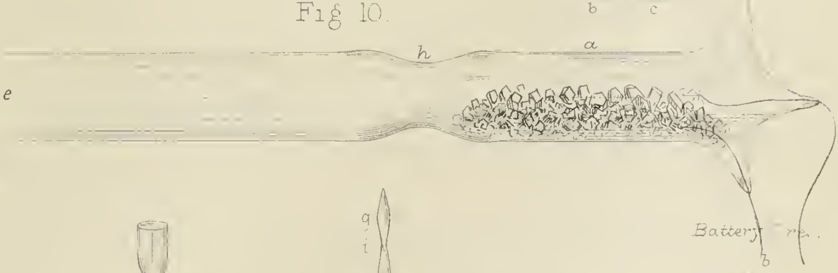


Fig. 9.

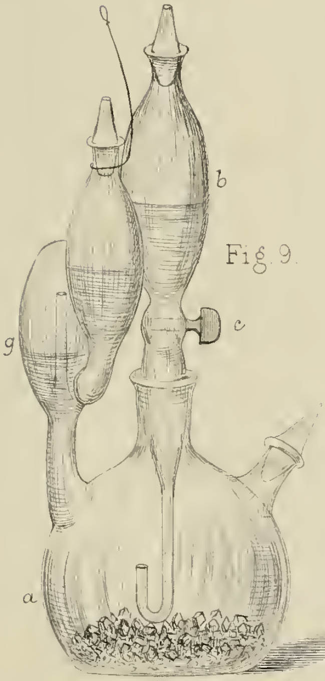


Fig 11.

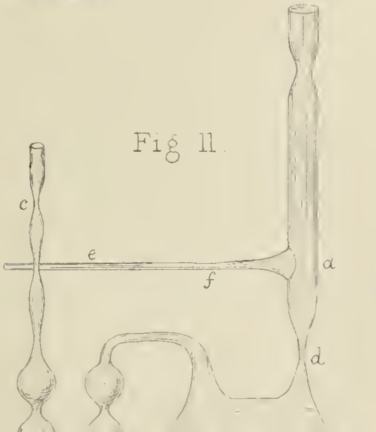


Fig. 12.

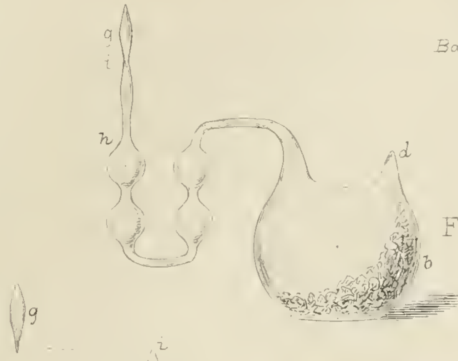
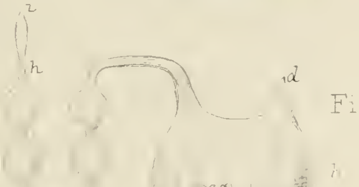
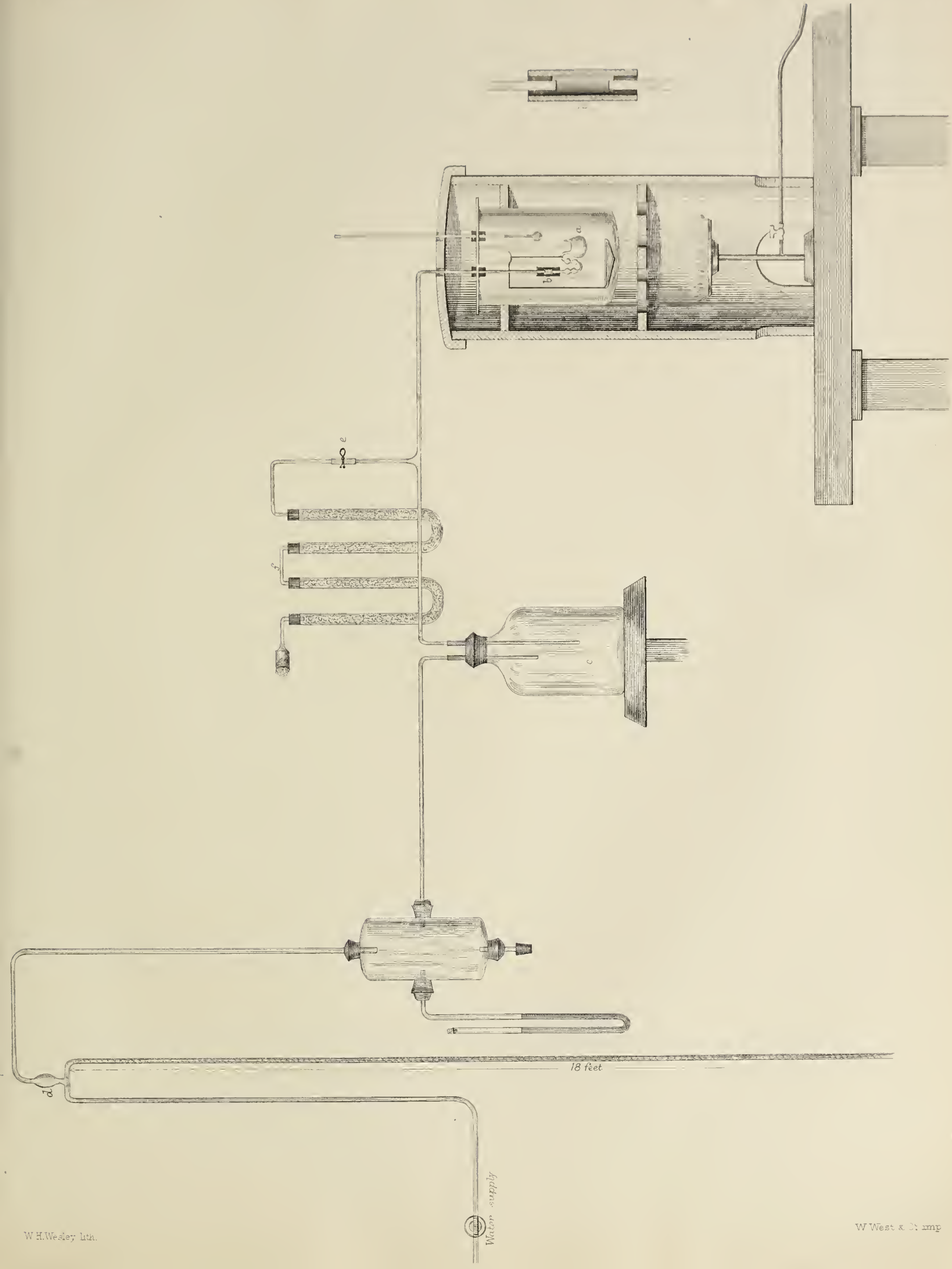


Fig. 13.



W.H.Wesley sc.

LIBR
OF THE
VERSITY of ILLINOI



W.H.Wesley lith.

W.West & Co imp.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

VII. *Magnetical Observations in the Britannia and Conway Tubular Iron Bridges.*

By Sir George Biddell Airy, *K.C.B., P.R.S., Astronomer Royal.*

Received October 12,—Read December 19, 1872.

It occurred to me some time since that it would be matter of interest to examine the character of the magnetic action of the iron in the Britannia and Conway Tubular Iron Bridges upon a magnetic needle within the tube. This was suggested to me by consideration, not so much of the mass and extent of the iron structure (although both, in the Britannia Bridge, are very great) as of the peculiar state of tremor to which the iron is continually subjected. After remarking, when within the tube of the Britannia Bridge, the disturbance of the iron produced by a passing train, my hand being firmly pressed against the iron wall, I described to the late Robert Stephenson my impression that the particles of the metal were in a state of "molecular shiver," and he replied that those words exactly represented his own idea on the agitation of the iron. All experiments appear to show that iron, in this state of tremor, is peculiarly subject to the inductive action of external magnetic force. When to this is added the consideration that the tubes have been unmoved in position, and that they have been subjected to this disturbance many times every day since their erection, it seems reasonable to conclude that they will exhibit the greatest amount of induced magnetism which it is possible for malleable iron to receive. I know not how far this susceptibility to magnetic action may depend on the quality of the iron; but I think it proper to state, on the authority of Mr. Edwin Clark, that the iron was made chiefly in Staffordshire and Coalbrookdale, a smaller portion in Derbyshire, and that it was the ordinary "best-best" plates of the day, and intended to be scrap-iron throughout.

My friend Mr. James Carpenter (then Assistant in the Royal Observatory) entered warmly into my views, and at my request undertook the conduct of the requisite observations; and I detached him for a few days (at my own pecuniary expense) from his duties at the Royal Observatory. Captain G..L. Tupman, R.M.A., who was at the time preparing himself in the use of instruments for observation of the Transit of Venus, gave his friendly assistance; and I am confident that the work undertaken by these gentlemen was executed with the greatest care and accuracy throughout.

On my explaining my wishes to S. Reay, Esq., Secretary of the London and North-Western Railway, I was quickly informed that the Directors of the Railway had issued instructions that every assistance should be given by their officers; and I was specially referred to J. O. Binger, Esq., District Superintendent at Chester, and Hedworth Lee, Esq., District Engineer at Holyhead. The observers, on their journey to Bangor, had interviews with these gentlemen, and with Mr. MacGuire and Mr. Macmillan, and explained fully the nature of the assistance which would be most useful to them. It was speedily arranged that the observers should be put in charge of Mr. Fletcher, foreman of the painters of the iron tube. It appears that it is necessary to give continual attention to the painting of the iron; and the men employed for this purpose acquire a knowledge of the details of the structure and a facility of moving about all parts which are not possessed by any other persons on the railway. The selection of Mr. Fletcher to communicate immediately with the observers was therefore eminently judicious, and was attended with the best possible effect. Four of his men were in constant attendance on the observers, within the tube; and to their faithful and zealous attention the success of the enterprise is mainly due. Policemen were stationed near the ends of the tube, and signalmen in proper positions, to give timely notice of the approach of trains; and every person connected with the railway was evidently anxious to do his best to aid the party. I cannot too strongly express our obligations to the company and officers of the London and North-Western Railway for their cordial assistance in every part of the experiment.

It was obviously unnecessary to examine the magnetic circumstances in proximity to the iron plates (a condition which may be obtained anywhere), and I therefore determined on making observations solely in the very axis of each tube, as nearly as possible at the centre of its height and the centre of its breadth. The selection of points of observation, as regards the ordinate longitudinal to the tubes, was determined by their structure. The tubes and the land from which they start on both sides of the Menai Strait are more than 100 feet above the level of the sea, and from the brow on each side, from which the tubes start, there is a sloping bank to the water's edge. At the foot of the bank on each side a tower is built; there is also a central tower on the Britannia Rock, in the middle of the strait. Thus each tube consists of four parts having five supports, called respectively The Carnarvon Abutment, The Carnarvon Land Tower, The Britannia Tower, The Anglesey Land Tower, and The Anglesey Abutment. The lengths of the four parts are nearly 90, 170, 170, and 80 yards. The four portions of each tube were built and raised independently, the ends of each being strengthened with iron frames, for sustaining the strains which are incidental to the supporting ends of a tube; but, after they were raised, the abutting ends were connected very strongly by riveted iron plates similar to those in other parts of the tube, and so arranged (by driving the rivets when the distant end of one of the tubes under the uniting process was somewhat raised) that there is a very strong tension in the upper part of the tube, at the place of junction, assisting to support the portions intermediate between two of the towers. The whole bridge consists, therefore, of two tubes, each entire from the Carnarvon Abutment to the Anglesey Abutment, but having greater quantities of iron at the ends and also on each of the three intermediate towers. It appeared to me, therefore, proper that observations should be taken at each of the five points of support (those at the two terminations being carefully taken in the transversal plane of the end of the iron work), and also in the middle of the length of each of the four partial tubes, making in all nine stations for each of the long tubes.

Besides these, it was necessary to select stations, external to the Bridge but in the prolongation of its central line, at which normal observations should be taken, to which those taken within the tubes should be referred. Good stations were found about 700 yards from the Carnarvon Abutment and 600 yards from the Anglesey Abutment.

The circumstances of the Conway Bridge, consisting of only one tube 140 yards long for each line of rails, were much simpler. It was only necessary to make observations at the terminal towers, called the Chester Tower and the Holyhead Tower, and in the middle of the length, for each of the parallel tubes. An external station was found at 700 yards distance from the Chester Tower; but none could be found at a greater distance than 80 yards from the Holyhead Tower. I do not, however, imagine that the action of the iron bridge was in any degree sensible at this distance.

The positions of the tubes of the two bridges with respect to the Magnetic Meridian, and the places of the observing-stations, will be understood from the plans in Plate XVIII.

For support of the instruments in the observations, remarking that the tubes of the Britannia Bridge vary in depth, in their interior, from 22 to 26 feet, I constructed a large wooden step-ladder, 12 feet high, with a flat stage for instruments on the top, supported by two legs striding apart to the breadth of 8 feet (embracing the rails of the railway), which were duly connected with the ladder by cross bars. This structure was found to be very firm. The various parts were so united by screws that they could be easily separated; and the men who attended on the observers were practised in the mounting and dismounting of the ladder-stage, till it was found that they could entirely remove the instruments and stage in one minute of time. This command of the apparatus enabled the observers to make their observations with little disturbance from passing trains. For use in the tubes of the Conway Bridge, which are not so deep as those of the Britannia Bridge, the step-ladder was lowered. It was necessary, in most cases, to use the light of a lamp.

The magnetic observations to be made at all the stations were:—of the direction of total horizontal force, of the magnitude of total horizontal force, and of the magnitude of total vertical force. They were thus conducted:—

The direction of horizontal force was found by observing with a prismatic compass the apparent direction of the tube. From the land stations the direction of the tube's axis was observed without difficulty, and this was taken as the undisturbed or normal azimuth. In the tube stations the disturbed bearing of the end opening (when its centre could be well estimated), or that of a weighted rope hung from the top of the end frame, was observed. Six observations were made at each station. It is to be remarked that, with this instrument, apparent azimuths increase in the direction N.E.S.W., and therefore, in observing a fixed mark, an increase of reading implies that the needle has turned in the direction N.W.S.E.

The magnitude of horizontal force was found by use of a vibrating needle, the same which I used in the fundamental observations in the 'Rainbow' (Phil. Trans. 1839), and which was subsequently lent to Mr. RUNDELL and Staff-Captain EVANS for observations in the 'Great Eastern.' In consequence of the amount of vertical disturbance (to be mentioned hereafter), the needle was sometimes inclined to the horizontal plane so far as to render it necessary to raise the upper part of its case, but not so far as sensibly to change the time of its vibration. Three sets of vibrations, each set consisting of 20 vibrations, were usually observed. It is perhaps proper to remark that the actions of the magnetic bodies surrounding the needle were such that they did not produce a variation of force depending on the variable position of the needle in its arc of vibration, and thus the vibrations give a legitimate measure of the horizontal force.

The magnitude of vertical force was measured by use of a portable dip-instrument, Barrow 24, for the loan of which I am indebted to the courtesy of the Kew Committee. The dip-instrument is furnished with four needles, but only one (marked A 1) was used in these observations, and always with the pole B charged with red magnetism (not always dipping, as will be seen). Usually eight observations were made at each station, four being made by reversing the frame and reversing the needle-pivots on the frame, and four more by repeating that order. The poles were not reversed during the experiments, but they were reversed in some observations of dip at Greenwich. At Greenwich, before and after the experiments, and also at Bangor and Conway, the needle A_1 was compared with A_3. The results were not perfectly accordant, and did not enable me to judge with certainty whether the needle A_1 was sensibly out of balance; and I am inclined to believe that the dips at the experimental stations may be uncertain to the extent of 5′ or more. The dip was always observed in the plane of the apparent or disturbed magnetic meridian.

The first observation of the entire series was taken at Greenwich on 1872, July 31, and the last was taken at Greenwich on August 16.

I now proceed with tabular statements of the observations and their results. In explanation of the azimuths, it is to be remarked that from station 1 to 10 the observers advanced northward along the eastern tube of the Britannia Bridge, observing the apparent azimuth of the northern opening; and then from station 11 to 20 returned southward along the western tube, observing the apparent azimuth of the southern opening; to the latter series 180° will be applied in the following calculations. Similarly in the Conway Bridge, from station 24 to 27 the observers advanced westward along the northern tube; and by stations 28, 21, 22, 23 eastward along the southern tube: 180° will be applied to the latter.

No of Station.	Description of Station.	Apparent Azimuth.	Time of 20 vibrations.	Apparent Dip.
		° ′ ″	s	° ′ ″
1.	External Carnarvonshire Station	343 36 30	97·92	+69 28 49
2.	Carnarvon Abutment ....(E. tube)	362 4 10	60·43	+ 1 15 15
3.	Middle of Carnarvon Land Tube ....(E.)	366 41 40	106·20	+ 6 0 15
4.	Carnarvon Land Tower ....(E.)	361 4 10	115·60	+ 8 14 15
5.	Middle of Carnarvon Water Tube ....(E.)	361 58 20	108·37	− 2 55 38
6.	Britannia Tower ....(E.)	355 50 50	128·17	− 5 23 38
7.	Middle of Anglesey Water Tube .... (E.)	351 0 0	99·87	− 3 12 23
8.	Anglesey Land Tower ....(E.)	361 3 20	111·57	−15 19 0
9.	Middle of Anglesey Land Tube ....(E.)	353 36 40	112·23	+16 16 0
10.	Anglesey Abutment ....(E.)	352 50 0	66·77	+24 51 37
11.	External Anglesey Station	163 16 30	98·80	+69 33 23
12.	Anglesey Abutment..................................(W. tube)	183 3 20	68·93	+27 27 30
13.	Middle of Anglesey Land Tube ....(W.)	178 58 20	124·30	+16 39 15
14.	Anglesey Land Tower....................................(W.)	178 25 50	117·90	− 3 1 45
15.	Middle of Anglesey Water Tube ....(W.)	183 54 10	100·37	+ 0 49 15
16.	Britannia Tower ....(W.)	181 50 50	130·93	+ 3 20 30
17.	Middle of Carnarvon Water Tube......................(W.)	184 9 10	106·63	+ 1 19 45
18.	Carnarvon Land Tower ....(W.)	178 12 30	114·10	+ 9 17 45
19.	Middle of Carnarvon Land Tube ....(W.)	171 5 50	107·97	+15 11 15
20.	Carnarvon Abutment ....(W.)	171 13 20	62·33	− 4 4 0
21.	Holyhead Tower ....(S. tube)	169 58 20	126·07	+46 9 30
22.	Middle of Conway Bridge...................................(S.)	31 0 0	173·10	+32 17 0
23.	Chester Tower ....(S.)	154 47 30	131·30	+35 11 7
24.	External Denbighshire Station	263 34 30	99·13	+69 9 30
25.	Chester Tower ....(N. tube)	323 10 0	142·60	+44 31 45
26.	Middle of Conway Bridge ....(N.)	215 47 30	171·17	+18 30 45
27.	Holyhead Tower ....(N.)	338 40 0	105·93	+38 30 30
28.	External Carnarvonshire Station	85 48 20	98·73	+69 0 38

It appears to me probable that the difference between the corresponding numbers at the two external stations of each bridge is purely accidental; the only difference deserving attention is that at Conway, and there, as appears to me, the action of the iron bridge cannot explain it. I have therefore adopted for each bridge the mean of the two observed numbers for each element at the external stations as the true normal number peculiar to that locality; and, as regards each pair of collateral stations in the two tubes of each bridge, I have thought it best to take the mean. Theoretically, it appears to me that the longitudinal action and the vertical action of each tube increase the longitudinal disturbance and the vertical disturbance in the other tube, but that the transversal horizontal action of one tube is scarcely sensible in the other tube; this view, however, is not borne out by the final results.

Taking the means, then, for the external stations as thus described, the numbers in the 3rd, 4th, and 5th columns of the following Table are obtained. Assuming, in the case of each bridge, the total normal horizontal force=1, the normal horizontal force longitudinal to the bridge will =cosine azimuth of axis of bridge, the normal horizontal force transversal to the bridge, towards the right, =sine azimuth, and the normal vertical force=tangent of dip. Thus the 6th, 7th, and 8th columns are formed.

Normal Local Elements.

Nos. of Stations.	Name of Bridge.	Apparent Azimuth of axis of tube.	Time of 20 vibrations.	Dip.	Longitudinal force.	Transversal force.	Vertical force.
		° ′ ″	s	° ′ ″			
1, 11.	Britannia	−16 33 30	98·36	69 35 41	+0·95850	+0·28500	+2·6882
24, 28.	Conway	−95 18 35	98·93	69 5 4	−0·09254	+0·99570	+2·6166

Proceeding now with the forces in the horizontal plane at each of the tube stations, the total horizontal force at each station is given by the formula

$$\left(\frac{\text{time of 20 vibrations in normal local elements}}{\text{time of 20 vibrations at the station}}\right)^2,$$

of which quantity the logarithm only is used; the longitudinal force at each station = horizontal force at station × cos disturbed azimuth, and the transversal force to the right = horizontal force at station × sine disturbed azimuth. The comparison of these with the longitudinal and transversal forces derived from the normal local elements gives the disturbances of magnetism in both directions at each station. Thus the following Table is formed:—

Forces in the Horizontal Plane at each Tube station.

Nos. of Stations.	Description of Stations.	Disturbed azimuth.	Logarithm of total horizontal force.	Longitudinal horizontal force.	Transversal horizontal force.	Longitudinal disturbance.	Transversal disturbance.
2, 20.	Carnarvon Abutment	− 3° 21′ 15″	0·40958	+2·5635	+0·1502	+1·6050	−0·1348
3, 19.	Middle of Carnarvon Land Tube...	− 1 7 15	9·92620	+0·8436	+0·0165	−0·1149	−0·2685
4, 18.	Carnarvon Land Tower	− 0 21 40	9·86538	+0·7335	+0·0046	−0·2250	−0·2804
5. 17.	Middle of Carnarvon Water Tube..	+ 3 3 45	9·92282	+0·8360	−0·0447	−0·1225	−0·3297
6, 16.	Britannia Tower	− 1 9 10	9·76076	+0·5763	+0·0116	−0·3822	−0·2734
7, 15.	Middle of Anglesey Water Tube...	− 2 32 55	9·98458	+0·9642	+0·0429	+0·0057	−0·2421
8, 14.	Anglesey Land Tower	− 0 15 25	9·86626	+0·7349	+0·0033	−0·2236	−0·2817
9, 13.	Middle of Anglesey Land Tube ...	− 3 42 30	9·84000	+0·6904	+0·0475	−0·2681	−0·2376
10, 12.	Anglesey Abutment	− 2 3 20	0·32254	+2·1002	+0·0754	+1·1417	−0·2096
23, 25.	Chester Tower	− 31 1 15	9·71754	+0·4472	+0·2689	+0·5397	−0·7268
22, 26.	Middle of Conway Bridge	−146 36 15	9·51892	−0·2758	+0·1818	−0·1832	−0·8139
21, 27.	Holyhead Tower	− 15 40 50	9·86174	+0·7003	+0·1966	+0·7928	−0·7991

The principles of the treatment of the vertical forces are similar. The vertical force at each station is found by the formula, total horizontal force at station × tan disturbed dip; and the vertical disturbance is the difference between this number and the vertical force in the first Table. Thus the following Table is formed:—

Vertical Force at each of the Tube stations.

Nos. of Stations.	Description of Stations.	Disturbed dip.	Vertical force.	Vertical disturbance.
2, 20.	Carnarvon Abutment	− 1° 24′ 22″	−0·0630	−2·7452
3, 19.	Middle of Carnarvon Land Tube ...	+10 35 45	+0·1578	−2·5244
4, 18.	Carnarvon Land Tower	+ 8 46 0	+0·1131	−2·5691
5, 17.	Middle of Carnarvon Water Tube ...	− 0 47 57	−0·0117	−2·6999
6, 16.	Britannia Tower	− 1 1 34	−0·0103	−2·6985
7, 15.	Middle of Anglesey Water Tube......	− 1 11 35	−0·0291	−2·7083
8, 14.	Anglesey Land Tower	− 9 10 22	−0·1187	−2·8069
9, 13.	Middle of Anglesey Land Tower......	+16 27 37	+0·2044	−2·4838
10, 12.	Anglesey Abutment	+26 9 34	+1·0322	−1·6560
23, 25.	Chester Tower	+39 51 26	+0·4357	−2·1809
22, 26.	Middle of Conway Bridge	+25 23 52	+0·1568	−2·4598
21, 27.	Holyhead Tower	+42 20 0	+0·6626	−1·9540

Finally, in order to obtain results which appear to possess more of a physical character, we shall assume that each of the disturbances (longitudinal, transversal, vertical) is produced simply by each of the normal forces (longitudinal, transversal, vertical); and we shall exhibit the proportion of the disturbance produced to the force which produces it.

Values of the fraction $\dfrac{\text{Disturbance of magnetic force}}{\text{Normal force which produces it}}$.

Description of Stations.	Fraction for longitudinal force.	Fraction for transversal force.	Fraction for vertical force.
Carnarvon Abutment	+1·6745	−0·4729	−1·0212
Middle of Carnarvon Land Tube	−0·1199	−0·9421	−0·9391
Carnarvon Land Tower	−0·2348	−0·9838	−0·9556
Middle of Carnarvon Water Tube	−0·1278	−1·1570	−1·0044
Britannia Tower	−0·3987	−0·9593	−1·0038
Middle of Anglesey Water Tube	+0·0059	−0·8494	−1·0075
Anglesey Land Tower	−0·2332	−0·9885	−1·0442
Middle of Anglesey Land Tube	−0·2797	−0·8335	−0·9240
Anglesey Abutment	+1·1911	−0·7355	−0·6160
Chester Tower	−5·8326	−0·7299	−0·8335
Middle of Conway Bridge	+1·9801	−0·8174	−0·9400
Holyhead Tower	−8·5674	−0·8026	−0·7468

The numbers in the third and fourth columns of this Table, including the Conway as well as the Britannia Bridge, present a good agreement. Their general result is this: that in the axis of a rectangular tube, at all parts except very near the ends, the action of external magnetic forces in planes normal to the axis is absolutely destroyed. In the second column for the Britannia Bridge there is one anomaly at Middle of Anglesey Water Tube of which I can give no explanation. It is a certain fact of observation; it may arise from some peculiar steely character of the iron in its neighbourhood. Putting this aside, the other numbers for the Britannia Bridge are exactly what we should have expected from a structure so closely resembling a bar magnet; the longitudinal force is greatly increased at the ends, but is diminished in all other points; not, however, as in the transversal forces, to its complete annihilation, but diminished by about one fourth part. For all these cases the circumstances of position of the bridge with respect to the magnetic meridian are favourable.

For the second column, as applying to the Conway Bridge, the position is unfavourable, the axis of the bridge being very nearly transversal to the magnetic meridian, and the denominator of the fraction consequently very small. Still, referring to the last Table but two, there can be no doubt that the character of the forces is such as we should have expected in a tube whose length is directed in the N.W. quadrant, instead of the S.W. I can give no accurate explanation of this phenomenon. It would almost seem that, even in a structure so simple and so rigorously rectangular as the bridge-tube, we cannot treat the effect of one of the rectangular forces as being strictly confined to that rectangular direction; yet I do not see how the transversal actions can explain longitudinal force in one direction rather than in the other.

It may be worth adding that, in the course of this discussion, I have conceived that possibly some difference of effects may have arisen from the difference in the direction of the iron planks of which different parts of the bridges are built; and to test this, I have had square plates constructed of narrow planks, riveted together like those of the bridges, the trials of which were thus conducted:—First, the square plate was placed on the equatoreal plane of a "Magnetic Anvil" and carefully hammered, and was then placed under a prismatic compass with which a distant object was viewed, with its planks directed at one time N.E. or S.W., and at another time N.W. or S.E.; it gave no sign of quadrantal deviation. Second, the plate was placed on the dip-plane and hammered with the same violence (as well as I could judge), with each of its four edges downwards in four different examinations, and after each hammering was placed under the compass, with the edge that had been lowest placed alternately E. and W.; the deviations produced were sensibly the same (at least I could not certainly answer for any difference), whether the sides of the planks had been horizontal or vertical during the hammering upon the dip-surface. Both experiments appear to show that none of the magnetic results in the bridge-experiments can depend on the direction of the iron planks.

I may, however, mention that in the horizontal structures forming the roof and floor of the bridge the planks are longitudinal, and that in the vertical side walls the planks are vertical.

Postscript.

Received October 22, 1872.

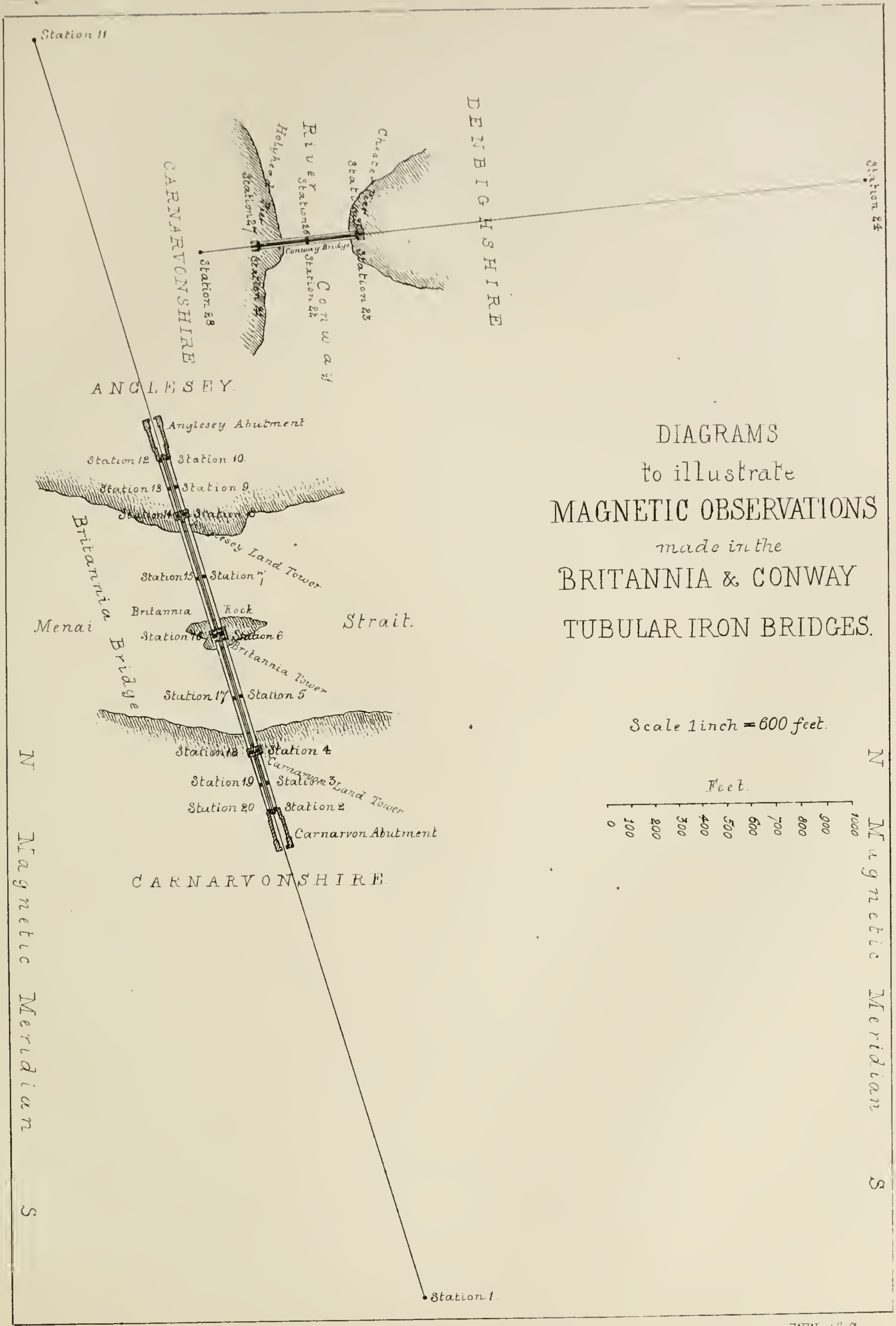
With the hope of obtaining some information which might explain the anomaly in the amount of longitudinal disturbance in the Anglesey Water Tubes, I inquired of Edwin Clark, Esq. (under whose immediate superintendence the Britannia and Conway Bridges were constructed) whether there was any thing peculiar in the iron material of those tubes. Mr. Clark informed me that there was no known difference in the iron; but he reminded me that the Eastern Anglesey Water Tube was the tube first raised, and that it was this tube which, in consequence of the bursting or rather longitudinal disruption of one of the cylinders of the hydrostatic press by which it was raised, suffered at one end a fall of 8 or 9 inches. The details of this accident are given in the work 'On the Britannia and Conway Tubular Bridges,' pages 690 &c. There is no doubt that the strain then sustained by the tube greatly exceeded any other strain to which it has been exposed. On referring to the first Table, it will be seen that the times of vibration are disturbed in both the Anglesey Water Tubes, slightly more so in the eastern than in the western tube. If, therefore, the magnetic longitudinal influence exhibited within the western tube was really affected by this accident, and to the supposed amount (a thing on which I have no doubt), it would seem that the longitudinal effect of the eastern tube is nearly as great at an external point (at a distance equal to that of the collateral tubes in this bridge, 27 feet centre to centre) as in the centre of that eastern tube—a law which it is impracticable to verify in this instance, but which I think is very probably correct.

Mr. Clark remarks, "It would indeed be extremely interesting if you discovered the effects of a fall that took place a quarter of a century ago by a magnetic experiment made now." I believe that this point has really been gained.

The tubes of the Britannia Bridge were built and riveted with their lengths very nearly in the magnetic E.–W. direction, in which state the terrestrial magnetism would have very little influence on them. It seems probable, therefore, that the magnetism which they now possess has been received entirely since their establishment on their piers.

With regard to the anomaly of the longitudinal forces in the Conway Bridge, I find that the tubes were built and riveted with the Holyhead end about 48° 50′ west of the magnetic N.; in this state the tubes would receive much longitudinal magnetism with the sign that is shown in our observations. Each tube was then mounted with its axis nearly magnetic E.–W.; and it appears that the forces subsequently acting upon it have not sensibly altered the longitudinal magnetism impressed on it during its construction.

1872, *October* 21.



DIAGRAMS
to illustrate
MAGNETIC OBSERVATIONS
made in the
BRITANNIA & CONWAY
TUBULAR IRON BRIDGES.

Scale 1 inch = 600 feet.

W.H. Wesley lith.
W West & Co imp.

VIII. *Magnetic Survey of Belgium in* 1871. *By the Rev.* STEPHEN J. PERRY. *Communicated by General Sir* EDWARD SABINE, *F.R.S.*

Received December 24, 1872,—Read February 6, 1873.

PREVIOUS to the year 1871 few observations had been made in Belgium for determining the elements of terrestrial magnetism, if we except the series which has been carried on without interruption at the Royal Observatory since 1828. Before this latter date the Intensity and Dip had never been ascertained, and there existed only two reliable measures of the Declination, viz. that of 20° 35'·5 for Ostend, which PIGOT observed in 1772, and the other for Nieuport, which, at about the same date, was found by MANN to be 19° 48'·5. Since 1828 the observations made at any other station besides Brussels have not been numerous. In 1854 the Dip was measured at Antwerp, Courtray, Ghent, Mons, and Ostend; the Horizontal Force was found at Liége and Louvain in 1829, 1850, and 1854, and also at Namur in 1829; and the three elements were observed in 1859 at Ghent and Mechlin. The results of these various observations are collected in the work entitled "La Physique du Globe," by M. A. QUETELET, and in Dr. LAMONT'S 'Untersuchungen über die Richtung und Stärke des Erdmagnetismus in Belgien,' &c. The above being the only determinations of the magnetic elements, there is an obvious want of a complete series of observations at a sufficient number of stations, and the survey which forms the subject of the present paper was undertaken with the view of supplying the required series of connected values of the three elements.

The instruments employed in this survey were the BARROW dip-circle, the JONES unifilar, and the FRODSHAM chronometer of Stonyhurst Observatory, and an excellent theodolite by TROUGHTON and SIMMS for determining the azimuth of the fixed points for the Declination. For this last instrument I was indebted to the kindness of JAMES SHOOLBRED, Esq., C.E. All necessary information respecting the magnets and instruments will be found in the paper on the Magnetic Survey of the West of France printed in the Phil. Trans. of 1870.

The methods of observation and reduction were identical with those adopted in the preceding surveys.

At all the stations in Belgium the Dip was observed by Mr. W. CARLISLE, the readings for each needle being never less than 32; the remaining elements were determined by myself.

In forming the equations of condition for the determination of the lines of equal Dip, Declination, and Intensity, the Royal Observatory of Brussels has been chosen as the origin of coordinates.

TABLE I.

Station.	Latitude.	Longitude.	Difference in miles of		Place of observation.
			Lat.	Long.	
	° ′ ″	m s			
Aix-la Chapelle	50 46 0	6 51	− 6·0	+75·1	18 Aurelius Strasse.
Alost	50 56 18	1 19	+ 5·9	−14·4	Garden of the College.
Antwerp	51 13 15	0 8	+25·4	+ 1·4	Courte rue Neuve.
Arlon	49 41 0	5 39	−80·8	+63·6	Rue du Luxembourg 46.
Bruges	51 12 30	4 35	+24·6	−49·8	Rue Flamande 60.
Brussels	50 51 11	0 0	0·0	0·0	Royal Observatory, 131 rue Royale.
Courtray	50 49 0	4 21	− 2·5	−47·6	Garden near Church of St. Michael.
Ghent	51 3 12	2 34	+13·8	−28·0	Rue d'Assaut 26.
Liége	50 39 0	4 51	−14·0	+53·4	Collége St. Servais.
Lierre	51 7 0	0 47	+18·2	+ 8·5	Vineyard close by Parish Church.
Louvain	50 53 27	1 19	+ 2·6	+14·3	Rue des Récollets 11.
Mechlin	51 1 45	0 26	+12·2	+ 4·7	Boulevards des Arbalétriers 83.
Mons	50 27 0	1 41	−27·9	−18·6	Collége St. Stanislas.
Namur	50 28 2	1 56	−26·7	+21·3	Collége N. D. de la Paix.
Ostend	51 13 47	5 48	+26·0	−63·0	Garden near the Church.
Spa	50 29 0	5 55	−25·5	+65·2	Rue de Wauxhall 43.
Tournay	50 36 22	3 55	−17·1	−43·1	Collége Notre Dame.
Tronchiennes	51 3 12	2 49	+13·8	−30·8	Ancienne Abbaye.
Turnhout	51 19 0	2 11	+32·1	+23·7	Collége St. Joseph.
Verviers	50 36 0	5 55	−17·5	+65·1	Collége St. François Xavier.

A comparison of the large atlases of FERRARIS, PHILIP, and the Useful Knowledge Society have supplied the required data for the above geographical latitudes and longitudes, whenever these could not be obtained directly from the 'Connaissance des Temps.'

The Magnetic Dip.

As this element has been observed almost invariably with each of the three needles employed throughout the survey, any very accurate comparison of the readings obtained with the several needles is thus rendered unnecessary. It may suffice to remark that needles Nos. 2 & 3 give mean results which are scarcely perceptibly at variance, whilst the readings of No. 1 are about 1′·5 in excess of the mean of the other two.

TABLE II.

Station.	Date.	G.M.T.	Dip.			
			Needle No. 1.	Needle No. 2.	Needle No. 3.	Mean.
	1871.	h m				
Antwerp	Aug. 5	9 5 A.M.	67° 4′ 29″			
		10 50 ,,	....	67° 0′ 8″		
		3 15 P.M.	....	....	66° 59′ 19″	67° 1′ 19″
Brussels, 131 rue Royale	,, 8	10 15 A.M.	67 5 57			
		3 15 P.M.	....	67 12 34		
		4 50 ,,	....	....	67 8 50	67 9 7
Brussels Observatory	,, 9	10 50 A.M.	66 56 34			
		12 15 P.M.	....	67 1 34	....	66 59 4
Louvain	,, 11	10 10 A.M.	66 58 12			
		2 55 P.M.	....	66 54 11		
		4 55 ,,	....	....	66 53 38	66 55 12
Mechlin	,, 14	8 10 A.M.	66 47 39			
		9 55 ,,	....	66 40 36	....	66 44 8
Lierre	,, 14	4 0 P.M.	66 59 30			
	,, 15	8 5 A.M.	....	66 51 47		
		9 55 ,,	....	....	67 0 19	66 58 12
Turnhout	,, 16	10 20 ,,	67 10 6			
		4 15 P.M.	....	67 6 2		
		5 44 ,,	....	....	67 7 56	67 8 1

TABLE II. (continued).

Station.	Date.	G.M.T.	Dip.			
			Needle No. 1.	Needle No. 2.	Needle No. 3.	Mean.
	1871.	h m	° ′ ″	° ′ ″	° ′ ″	° ′ ″
Verviers	Aug. 23	8 40 A.M.	66 47 8			
		10 15 ,,	....	66 40 55		
		11 35 ,,	....	....	66 44 49	66 44 17
Liége	,, 25	7 45 ,,	66 29 47			
		2 50 P.M.	....	66 28 28		
	,, 26	9 35 A.M.	....	....	66 28 45	66 29 0
Aix-la-Chapelle	,, 26	4 30 P.M.	66 38 17			
		5 45 ,,	....	66 43 49		
	,, 28	9 10 A.M.	....	....	66 36 8	66 39 25
Spa	,, 29	8 10 ,,	66 40 34			
		9 30 ,,	....	66 41 11		
		11 0 ,,	....	....	66 39 15	66 40 20
Arlon	,, 31	8 45 ,,	65 56 23			
		10 10 ,,	....	65 55 17		
		11 10 ,,	....	....	65 55 4	65 55 35
Namur	Sept. 2.	8 40 ,,	66 35 34			
		9 40 ,,	....	66 29 19		
		10 50 ,,	....	....	66 35 21	66 33 25
Mons	,, 4.	2 45 P.M.	66 33 29			
		3 50 ,,	....	66 38 39		
		4 50 ,,	....	....	66 34 20	66 35 29
Tournay	,, 6.	3 10 ,,	66 42 15			
		4 20 ,,	....	66 38 34		
		5 25 ,,	....	....	66 36 4	66 38 58
Courtray	,, 7.	3 30 ,,	66 41 25			
		4 35 ,,	....	66 38 19		
	,, 8.	7 45 A.M.	....	....	66 45 38	66 41 47
Ghent	,, 8.	3 20 P.M.	67 13 34			
	,, 10.	8 0 A.M.	....	67 14 12		
		9 18 ,,	....	....	67 15 15	67 14 20
Ostend	,, 11.	4 35 P.M.	67 14 20			
		5 25 ,,	....	67 16 26		
	,, 12.	4 15 ,,	....	....	67 10 19	67 13 42
Bruges	,, 13.	9 16 A.M.	67 14 35			
		11 10 ,,	....	....	67 7 21	
	,, 14.	4 40 P.M.	....	67 9 4	....	67 10 20
Tronchiennes	,, 15.	3 30 ,,	67 21 35			
		4 30 ,,	....	67 22 35		
	,, 16.	8 55 A.M.	....	....	67 23 47	67 22 39
Alost	,, 18.	3 14 P.M.	67 15 28			
		4 15 ,,	....	67 11 12		
	,, 19.	9 34 A.M.	....	....	67 14 0	67 13 33
Brussels, 131 rue Royale	,, 20.	4 50 P.M.	67 9 8			
	,, 23.	8 35 A.M.	....	67 6 39		
	,, 25.	7 45 ,,	....	....	67 2 51	67 6 13
Brussels Observatory	,, 22.	10 35 ,,	67 1 21			
		2 0 P.M.	....	66 58 12		
		3 5 ,,	....	....	67 1 2	67 0 12

Expressing the mean values in decimals of a degree, and subtracting 65° from each, we obtain the equations required for determining the distance apart, and the inclination to the meridian, of the lines of equal Dip.

$$\begin{aligned}
1{\cdot}657 &= \delta - 75{\cdot}1x - 6{\cdot}0y \\
2{\cdot}226 &= \delta + 14{\cdot}4x + 5{\cdot}9y \\
2{\cdot}022 &= \delta - 1{\cdot}4x + 25{\cdot}4y \\
0{\cdot}926 &= \delta - 63{\cdot}6x - 80{\cdot}8y \\
2{\cdot}172 &= \delta + 49{\cdot}8x + 24{\cdot}6y \\
1{\cdot}696 &= \delta + 47{\cdot}6x - 2{\cdot}5y \\
2{\cdot}239 &= \delta + 28{\cdot}0x + 13{\cdot}8y
\end{aligned}$$

$$\begin{aligned}
1{\cdot}484&=\delta-53{\cdot}4x-14{\cdot}0y\\
1{\cdot}970&=\delta-8{\cdot}5x+18{\cdot}2y\\
1{\cdot}920&=\delta-14{\cdot}3x+2{\cdot}6y\\
1{\cdot}736&=\delta-4{\cdot}7x+12{\cdot}2y\\
1{\cdot}591&=\delta+18{\cdot}6x-27{\cdot}9y\\
1{\cdot}557&=\delta-21{\cdot}3x-26{\cdot}7y\\
2{\cdot}228&=\delta+63{\cdot}0x+26{\cdot}0y\\
1{\cdot}672&=\delta-65{\cdot}2x-25{\cdot}5y\\
1{\cdot}650&=\delta+43{\cdot}1x-17{\cdot}1y\\
2{\cdot}378&=\delta+30{\cdot}8x+13{\cdot}8y\\
2{\cdot}134&=\delta-23{\cdot}7x+32{\cdot}1y\\
1{\cdot}738&=\delta-65{\cdot}1x-17{\cdot}5y
\end{aligned}$$

The solution of these equations of condition, found by the method of least squares, is $\delta=1{\cdot}87299$, $x=0{\cdot}0013762$, $y=-0{\cdot}0104147$.

The computed value of the Dip at the central station is therefore 66°·87299, the direction of the Isoclinals being from N. 82° 28′ 19″·4 E. to S. 82° 28′ 19″·4 W., and the distance between stations, whose Dips differ by 0°·5, 47·6 miles.

The Dip at the several stations obtained from this calculated data, and compared with the observed mean values, furnishes the following Table of errors:—

TABLE III.

Station.	Observed Dip.	Computed Dip.	Errors.
Aix-la-Chapelle	1·657	1·708	−0·051
Alost	2·226	1·954	+0·272
Antwerp	2·022	2·136	−0·114
Arlon	0·926	0·943	−0·017
Bruges	2·172	2·198	−0·026
Courtray	1·696	1·912	−0·216
Ghent	2·239	2·056	+0·183
Liége	1·484	1·654	−0·170
Lierre	1·970	2·051	−0·081
Louvain	1·920	1·880	+0·040
Mechlin	1·736	1·994	−0·258
Mons	1·591	1·608	−0·017
Namur	1·557	1·566	−0·009
Ostend	2·228	2·229	−0·001
Spa	1·672	1·517	+0·155
Tournay	1·650	1·754	−0·104
Tronchiennes	2·378	2·059	+0·319
Turnhout	2·134	2·174	−0·040
Verviers	1·738	1·601	+0·137

The probable error at any one station will therefore be ±0·10445, whilst that of the mean Dip at the central station is ±0·02185.

Referring now to previous observations, we shall be able to ascertain approximately the secular variation of the Dip. The only determinations of this magnetic element for stations out of Brussels are those of M. MAHMOUD EFFENDI in 1854 and of Dr. LAMONT in 1858, and these will serve to form the following Tables.

TABLE IV.

Station.	Dip, 1854.	Dip, 1871.	Diff. of Epoch.	Diff. of Dip.	Yearly rate.
Antwerp..............	67°·875	67°·022	17	−0·853	−0·050
Courtray	67·655	66·696	”	−0·959	−0·056
Ghent..................	67·833	67·239	”	−0·594	−0·036
Mons	67·383	66·591	”	−0·792	−0·047
Ostend	68·047	67·228	”	−0·819	−0·048
Brussels	67·663	66·994	”	−0·669	−0·039
				Mean for 1862·5...	−0·046

TABLE V.

Station.	Dip, Jan. 1, 1858.	Dip, Sept. 1, 1871.	Diff. of Epoch.	Diff. of Dip.	Yearly rate.
Aix-la-Chapelle......	67°·445	66°·657	13⅔	−0·788	−0·058
Ghent..................	68·002	67·239	”	−0·763	−0·056
Mechlin	67·643	66·736	”	−0·907	−0·066
Brussels	67·663	66·994	”	−0·669	−0·049
				Mean for 1864·8...	−0·0573

The values for Ghent and Brussels in the first column of figures of Table IV. do not inspire much confidence, as the latter is identical with LAMONT's value for 1858; and the former is much smaller than the corresponding number in Table V., although observed four years previously.

Table V. gives a secular variation which lies about midway between the values −0·062 and −0·054 found respectively for the West and East of France. Table IV. would make the secular variation −0·050, if we neglected the two doubtful quantities.

Dr. LAMONT gives −0·0417 as the annual decrease for 1858, which would indicate an acceleration of the yearly rate. We know, however, from the continuous series of observations made at the Brussels Observatory, and published in its 'Annuaire' by the eminent Director, M. A. QUETELET, that the annual decrease has been gradually diminishing from 0°·0527 in 1830 to 0°·0194 in 1865, the yearly variation being 0·00095. The extreme values of the Dip observed at the Royal Observatory at Brussels were 68° 56′·5 in 1827·8, and 67° 8′·0 in 1871·5.

The Magnetic Intensity.

TABLE VI.

Station.	Date.	G.M.T.	Distance of centres of magnets.	Temp.	Observed deflection.	Log $\frac{m}{X}$.
	1871.					
Antwerp	Aug. 5	4 3 P.M.	1·0	67°·1	13° 26′ 52″	9·06882
		4 26	1·3	65·8	6 5 33	9·06927
Brussels Observatory.	„ 9	11 2 A.M.	1·0	76·9	13 20 52	9·06638
		11 28	1·3	77·8	6 1 51	9·06578
Brussels, 131 rue Royale.	„ 10	4 36 P.M.	1·0	78·0	13 26 58	9·06970
Louvain	„ 11	10 43 A.M.	1·0	78·9	13 20 18	9·06624
		11 14	1·3	79·7	6 2 31	9·06674
Turnhout	„ 16	4 58 P.M.	1·0	74·8	13 21 4	9·06633
		5 26	1·3	73·5	6 3 9	9·06701
Liége	„ 24	11 6 A.M.	1·0	72·4	13 8 42	9·05950
		11 31	1·3	71 6	5 57 12	9·05972
Aix-la-Chapelle	„ 28	9 25	1·0	62·9	13 12 15	9·06073
		9 49	1·3	63·0	5 58 27	9·06059
Spa	„ 29	9 40	1·0	66·1	13 6 17	9·05773
		10 6	1·3	66·7	5 57 0	9·05911
Arlon	„ 31	4 5 P.M.	1·0	71·9	12 48 10	9·04820
		4 34	1·3	70·2	5 48 1	9·04832
Namur	Sept. 2	8 28 A.M.	1·0	73·9	13 13 12	9·06205
		8 56	1·3	75·1	5 58 50	9·06196
Mons	„ 4	2 41 P.M.	1·0	78·0	13 7 32	9·05929
	„ 5	9 44 A.M.	1·0	67·2	13 8 54	9·05922
		10 8	1·3	67·7	5 56 54	9·05906
Tournay	„ 6	3 58 P.M.	1·0	81·5	13 8 29	9·06009
		4 23	1·3	81·0	5 56 59	9·06017
Courtray	„ 8	8 16 A.M.	1·0	66·2	13 11 34	9·06059
		8 38	1·3	66·1	5 58 12	9·06052
Ghent	„ 9	4 10 P.M.	1·0	67·0	13 26 35	9·06866
		4 37	1·3	65·9	6 5 5	9·06874
Ostend	„ 11	5 55	1·0	69·1	13 27 30	9·06931
	„ 12	10 22 A.M.	1·0	67·8	13 27 8	9·06901
		10 45	1·3	67·6	6 5 12	9·06900
Bruges	„ 13	8 52	1·0	63·2	13 23 43	9·06687
		9 16	1·3	63·5	6 3 54	9·06715
Tronchiennes	„ 17	9 0	1·0	57·3	13 31 30	9·07055
		9 26	1·3	57·9	6 7 2	9·07046
Alost	„ 18	3 4 P.M.	1·0	58·8	13 20 49	9·06500
		3 28	1·3	58·1	6 2 37	9·06523
Brussels Observatory.	„ 22	2 16	1·0	59·7	13 17 13	9·06315
		2 41	1·3	60·3	6 1 4	9·06353
Brussels, 131 rue Royale.	„ 23	9 38 A.M.	1·0	56·0	13 27 53	9·06856
		10 7	1·3	57·1	6 5 26	9·06852

Date.	G.M.T.	Temp.	Time of one vibration.	Log mX.
	h m s			
Aug. 5	1 56 11 P.M.	75°·5	5·371295	0·25704
„ 9	12 42 6	81·1	5·35230	0·26039
	12 51 56	81·5	5·35120	0·26060
„ 10	7 25 11 A.M.	70·6	5·37560	0·25591
	8 12 50	72·3	5·376085	0·25595
	8 23 47	74·0	5·37571	0·25613
„ 11	3 34 42 P.M.	80·4	5·349085	0·26084
	3 43 37	80·3	5·34900	0·26085
„ 12	....	76·8	5·35183	0·26011
	8 32 24 A.M.	76·5	5·353795	0·25978
„ 17	8 26 46	76·7	5·35285	0·25997
	8 36 12	81·2	5·35436	0·26004
„ 24	9 31 46	71·3	5·31033	0·26656
		71·5	5·31292	0·26615
„ 28	7 46 4	62·8	5·309335	0·26601
	7 55 55	62·8	5·31196	0·26561
„ 29	8 3 54	63·1	5·30525	0·26667
	8 12 45	62·7	5·30567	0·26657
„ 31	10 36 13	77·7	5·24971	0·27710
	10 45 33	75·2	5·24888	0·27706
Sept. 2	9 34 44	80·1	5·32917	0·26418
		81·1	5·325875	0·26479
„ 5	7 54 21	66·4	5·321795	0·26427
		66·2	5·32092	0·26443
	8 24 10	67·4	5·32263	0·26428
		67·5	5·32108	0·26454
„ 6	5 3 40 P.M.	78·4	5·334665	0·26303
	5 25 35	77·6	5·332125	0·26340
	5 33 27	77·0	5·33175	0·26342
„ 7	3 23 43	71·2	5·32100	0·26483
	3 32 35	71·0	5·319665	0·26505
„ 9	2 44 46	71·6	5·38500	0·25463
	2 53 44	70·1	5·38271	0·25490
„ 11	4 42 40	70·2	5·38850	0·25395
	4 51 38	70·1	5·38596	0·25436
„ 13	10 11 34 A.M.	67·2	5·369495	0·25665
	10 20 31	68·2	5·36480	0·25748
„ 14	4 15 8 P.M,	63·1	5·35975	0·25786
	4 24 3	62·5	5·358125	0·25808
„ 16	10 37 5 A.M.	71·7	5·39492	0·25299
	10 46 5	70·3	5·391335	0·25346
„ 17	10 6 4	61·1	5·39083	0·25279
	10 15 3	61·9	5·39064	0·25286
„ 18	4 8 3 P.M.	59·8	5·356335	0·25822
	4 15 28	59·2	5·35571	0·25829
„ 22	3 30 16	60·4	5·34995	0·25945
	4 25 34	57·4	5·34281	0·26039
„ 23	11 1 57 A.M.	62·2	5·37873	0·25485

This Table, combined with the preceding determinations of the Dip, furnishes us with the means of calculating the components of the earth's magnetic intensity, and the magnetic moment of the vibration-needle.

TABLE VII.

Station.	H. F.	V. F.	T. F.	*m*.
Aix-la-Chapelle............	4·0045	9·2792	10·1064	0·46052
Alost	3·9503	9·4054	10·2019	0·45887
Antwerp......................	3·9274	9·2623	10·0606	0·46031
Arlon	4·1157	9·2121	10·0896	0·45991
Bruges	3·8934	9·2495	10·0355	0·45949
Brussels Observatory ...	3·9595	9·3252	10·1310	0·45956
Brussels, rue Royale ...	3·9189	9·2899	10·0827	0·45948
Courtray	4·0011	9·2889	10.1139	0·45999
Ghent.........................	3·9180	9·3382	10·1268	0·45892
Liége	4·0126	9·2211	10 0563	0·46024
Louvain......................	3·9544	9·2799	10·0873	0·46073
Mons	4·0048	9·2507	10·0804	0·45897
Namur	3·9923	9·2066	10·0349	0·46052
Ostend	3·9136	9·3226	10·1112	0·45881
Spa............................	4·0221	9·3267	10·1570	0·45976
Tournay	3·9958	9·2556	10·0813	0·45889
Tronchiennes	3·9016	9·3626	10·1430	0·45896
Turnhout	3·9522	9·3715	10·1708	0·46062

The second members of our original equations remaining each unchanged, but being three fewer in number, Table VII. will enable us at once to form the equations of condition for determining the nature of the lines of equal Horizontal Force. Their solution leads to the following values: H. F. $=3·96649$, $x=-0·00030302$, $y=0·0015808$.

Hence we find that there is a distance of 62·13 miles between the lines, indicating a difference of 0·1 in the Horizontal Force, and that this system of lines is inclined at an angle of 79° 8′ 55″·7 to the meridian, the direction being from N. 79° 8′ 55″·7 E. to S. 79° 8′ 55″·7 W. The differences between the observed results and those computed from the above data furnish a Table for calculating the probable errors.

TABLE VIII.

Station.	Observed.	Computed.	Obs.—Comp.
Aix-la-Chapelle..................	4·0045	3·9988	+0·0057
Alost	3·9503	3·9529	−0·0026
Antwerp	3·9274	3·9268	+0·0006
Arlon	4·1157	4·1138	+0·0019
Bruges	3·8934	3·9126	−0·0192
Courtray	4·0011	3 9562	+0·0449
Ghent..............................	3·9180	3·9363	−0·0183
Liége	4·0126	4·0050	+0·0076
Louvain..........................	3·9544	3·9668	−0·0124
Mons	4·0048	4·0052	−0·0004
Namur	3·9923	4·0153	−0·0230
Ostend	3·9136	3·9064	+0·0072
Spa..................................	4·0221	4·0267	−0·0046
Tournay	3·9958	3·9807	+0·0151
Tronchiennes	3·9016	3·9355	−0·0339
Turnhout	3·9522	3·9230	+0·0292

This gives us as the probable error for the mean at a single station ±0·01327, whilst that at the central station is ±0·00332.

In order to determine the secular change of the Horizontal Intensity, I have collected together, and reduced to English units, all the previous observations with which I am acquainted. The values for 1858 are taken from Dr. LAMONT's 'Erdmagnetismus,' and those for 1839 and 1854 may be found scattered in the introduction to the same work.

The numbers for 1829 and 1850 have been calculated from the data given in M. A QUETELET's treatise 'Sur la Physique du Globe;' and for 1850 I have made the supposition, which I find to be most consonant with the observations cited in the same work, that the ratio between the values of Horizontal Force at Paris and Brussels is on the whole nearly constant, that ratio being 0·961.

TABLE IX.

	1829.	1839.	1850.	1854.	1858.
Aix-la-Chapelle......	3·7661	3·8357	3·8796	3·9138	3·9349
Antwerp..............	....	....	....	3·8570	....
Ghent................	....	....	....	3·8208	3·8553
Liége	3·7984	3·8316	3·8755	3·8971	....
Louvain..............	3·7355	[3·8375]	[3·8835]	3·8730	....
Mechlin..............	....	....	....	....	3·9077
Namur	3·8208	....	....	....	....
Ostend	....	....	....	3·8056	....

Neglecting the two observations enclosed within brackets as being evidently too large, we find, by comparing these numbers with those given in Table VIII., the following values of the secular variation:—

TABLE X.

Epoch.........	1850.	1855.	1860·5.	1862·5.	1864·8.
Secular variation . .	0·00502	0·00547	0·00624	0·00552	0·00484

These results give +0·00542 as the mean value of the yearly change of the Horizontal Force for the epoch 1858·56. If we compare this with the annual increase deduced from the numerous observations made at Brussels between the years 1828 and 1860, we obtain a strong confirmation of the approximate correctness of the above value. HANSTEEN, LAMONT, and QUETELET have each expressed the law of increase of the Horizontal Force at Brussels in an analytical form, and these formulæ give respectively, for the epoch 1850, 0·005422, 0·005183, and 0·005617, as the secular increase. The mean of these differs from the result found above only by 0·000031. The acceleration for the same date given by HANSTEEN's formula is +0·000037; but QUETELET makes the increase of the yearly rate considerably more rapid. The concluded value of the secular variation of the Horizontal Force for Belgium is slightly in excess of that found for France from the surveys of 1868 and 1869.

We will now pass on to the discussion of the results obtained from the combined observations of the Dip and Horizontal Force at the several stations. Instead of forming new equations of condition with the values given in Table VII., and then solving them by the method of least squares, we can find the Intensity at each station by combining directly the computed as well as the observed values in Tables III. and VIII., and thence deduce the probable errors. Calling the Intensity deduced immediately from the observed Horizontal Force and Dip the observed Intensity, and that formed from the computed values the computed Intensity, we thus obtain the following results:—

TABLE XI.

Station.	Observed T. F.	Computed T. F.	Observed—Computed.
Aix-la-Chapelle	10·1064	10·1129	−0·0065
Alost	10·2049	10·0976	+0·1073
Antwerp	10·0606	10·1061	−0·0458
Arlon	10·0896	10·0917	−0·0021
Bruges	10·0355	10·0958	−0·0603
Courtray	10·1139	10·0886	+0·0253
Ghent	10·1268	10·0974	+0·0294
Liége	10·0563	10·1064	−0·0501
Louvain	10·0873	10·1024	−0·0151
Mons	10·0801	10·0882	−0·0078
Namur	10·0349	10·0965	−0·0616
Ostend	10·1112	10·0927	+0·0185
Spa	10·1570	10·1052	+0·0518
Tournay	10·0813	10·0859	−0·0046
Tronchiennes	10·1430	10·0966	+0·0164
Turnhout	10·1708	10·1125	+0·0583

The probable error at any station would thus be ±0·0321, whilst that of the mean is ±0·0080.

If we examine carefully the above figures, we find that the intensity increases as we proceed Northwards, but that the computed and observed values do not agree as to the Eastward or Westward tendency of the lines. The observed values in the West are greater than those in the East; but when the distance of each station from the meridian of Brussels is taken into account, the isodynamics are found to lie N.W. and S.E. This result is confirmed by combining the observed values by the method of least squares, which gives 10·10525 as the Total Force at the central station, and for the direction of the lines N. 70° 3′ 34″·6 W. to S. 70° 3′ 34″·6 E. That this is not caused by mere accidental errors at certain stations may be clearly shown; for, casting out those stations whose values are abnormal, and then recalculating the position of the lines of equal Intensity, we obtain a very similar result, even when as many as the six least reliable values are omitted. It is unfortunate that LAMONT'S survey of 1858 does not afford sufficient data for computing the isodynamics in Belgium alone for that epoch; but if we take his stations in Belgium and Holland, along with the neighbouring positions of Aix-la-Chapelle and Emden, we obtain nine equations of condition, which furnish lines of equal Intensity common to the two countries, and the direction of these is from N. 57° 6′ 6″·3 E. to S. 57° 6′ 6″·3 W. The probable errors are very nearly the same as those given above, being ±0·031582 for a single station and ±0·010527 for the mean. Of the three stations common to the two surveys the error for Aix-la-Chapelle is positive, whilst those of Ghent and Mechlin are negative. We have therefore indications of the existence of some great disturbing cause, which, by increasing the intensity at the eastern stations, tends to alter the direction of the isodynamics, and to remove further apart the lines passing through points whose Total Force differs by a constant quantity. A centre of local magnetic force may therefore not unnaturally be sought for in the eastern portion of Belgium, and the geological map of the country presents at once a ready answer to the inquiry. Starting from the neighbourhood of Mons, the vast coal tracks of Belgium, rich in iron ore, stretch across the eastern provinces, enveloping

Namur, Liége, and Aix-la-Chapelle, whilst the remainder of the country appears to be wholly devoid of all ferruginous wealth.

As a further series of observations in this region might throw considerable light on the subject of local magnetism, I purpose, unless the work is previously undertaken by others, again to observe the magnetic elements at closer stations within this interesting area.

If the disturbing cause is unchangeable, it will probably not interfere much with the determination of the secular variation of the Intensity as given in the annexed Table.

TABLE XII.

Station.	T. F., Jan. 1, 1858.	T. F., Sept. 1, 1871.	Diff. of Epoch.	Yearly change.
Aix-la-Chapelle......	10·2586	10·1064	$13\frac{2}{3}$	−0·01114
Ghent..................	10·2923	10·1268	„	−0·01211
Brussels...............	10·2869	10·1310	„	−0·01141
			Mean for 1864·8...	−0·01155

The Magnetic Declination.

In the observations for determining this element the azimuth of the fixed mark was found by taking transits of the sun with a transit-theodolite by SIMMS, kindly placed at my disposal for this survey by J. SHOOLBRED, Esq., C.E.; and the angular distance between the mark and the magnetic meridian was read on JONES'S unifilar. The same tripod served for both instruments. Before observing the sun, the fixed mark was bisected by the wire of the telescope, when the verniers of the azimuth-circle read 0° and 180°; thus the figures in the 6th column of Table XIV. are either the means of the readings as taken, or their defect from 360°.

The same magnet was used for all the observations, and each entry is the mean of the readings with erect and inverted scale. The scale-coefficient is 2′ 9″·805. For the observations at the Royal Observatory, Brussels, on the 9th of August, the zero-mark was not determined by observed transits with the theodolite, but a plumb-line was suspended in the meridian in front of the magnetic hut by aid of the large transit instrument of the observatory, and then the unifilar was adjusted in the meridian as accurately as this method would permit. The chronometer used was FRODSHAM'S No. 3148. The following Table contains the results of the comparisons made at Brussels and Stonyhurst:—

TABLE XIII.

Station.	Date.	G. M. T.	Error.	Daily Rate.
	1871.	h m	m s	
Stonyhurst Observatory	July 31	7 30 P.M.	+28 44·62	+3·09
Brussels Observatory	Aug. 9	7 30 „	+29 15·10	+3·39
„ „	Sept. 22	7 30 „	+32 21·90	+4·25
Stonyhurst........................	„ 29	11 0 „	+32 45·01	+3·24
„	Oct. 3	10 0 „	+32 55·69	+2·69

For the comparisons at the Brussels Observatory I am indebted to the kindness of M. E. QUETELET.

It was not possible to compare the chronometer oftener; but this is less to be regretted, as the behaviour of the instrument during the French surveys showed that it is not liable to any great change of rate whilst travelling, if carried always with care. As it was previously found that the rate of the chronometer could be more securely trusted than the deduced rates from observed altitudes of the sun, the latter were not observed in Belgium.

TABLE XIV.

Station.	Date.	Chronometer.	Error at Noon.	Daily Rate.	Azimuthal distance of sun from mark.	Azimuthal reading of magnet.	Azimuthal reading of mark.
	1871.	h m s	m s	s	° ′ ″	° ′ ″	° ′ ″
Antwerp …………………	Aug. 5	10 2 14·5 A.M.	+29 0·49	+3·39	44 47 30		
		10 18 4·1	……	……	39 52 15		
		10 42 9	……	……	………	244 54 37·0	
		10 49 5	……	……	………	244 54 56·5	256 35 30
Brussels Observatory …	„ 9	4 3 30 P.M.	29 14·04				
		4 20					
Brussels, 131 rue Royale	„ 10	8 14 42·8 A.M.	29 18·02	+4·245	47 34 0		
		8 22 0·9	……	……	45 59 30		
		9 25	……	……	………	171 19 42·35	
		9 30	……	……	………	171 19 42·35	159 11 40
Louvain …………………	„ 11	10 1 57·1	29 22·26	……	53 36 0		
		10 11 23·6	……	……	50 42 45		
		8 44 0	……	……	………	199 10 10·0	
		8 49 30	……	……	………	199 8 58·2	
		8 56 30	……	……	………	199 6 35·4	220 16 6·7
Turnhout …………………	„ 16	10 56 31·4	29 43·49	……	145 43 45		
		11 9 14·3	……	……	150 18 30		
		11 28 52·8	……	……	157 38 45		
		11 34 39·8	……	……	159 52 10		
		12 10 5 P.M.	……	……	………	117 1 33·9	
		12 16 47·5	……	……	………	117 3 24·3	
Liége …………………	„ 24	2 50 44·1	30 17·45	……	104 17 45		
		4 37 29·5	……	……	………	163 20 59·9	
		4 44 51·5	……	……	………	163 20 8·0	129 26 20
Aix-la-Chapelle…………	„ 26	3 56 18·9	30 25·94	……	24 36 45		
		4 7 31·5	……	……	27 5 0		
		4 15 37·9	……	……	28 50 0		
		4 50 45	……	……	………	219 25 3·5	
		4 58 15	……	……	………	219 23 26·2	
		5 6 30	……	……	………	219 21 16·4	101 26 30
Spa …………………	„ 29	11 16 25·3 A.M.	30 38·67	……	66 1 30		
		11 21 46·4	……	……	67 56 45		
		11 27 46·3	……	……	70 6 30		
		11 49 30	……	……	………	192 44 23	
		11 55 0	……	……	………	192 43 57	124 20 45
Arlon …………………	„ 31	2 14 19·0 P.M.	30 47·16	……	91 14 45		
		2 19 41·5	……	……	92 48 30		
		2 25 4·3	……	……	94 20 30		
		3 9 30	…. .	……	………	230 54 23·6	
		3 16 30	……	……	………	230 51 47·8	
		3 22 30	……	……	………	230 50 17·0	199 45 15
Namur …………………	Sept. 2	11 37 16·1 A.M.	30 55·65	……	60 42 30		
		11 43 55·5	……	……	63 6 30		
		11 48 42·1	……	……	64 50 30		
		11 7 51	……	……	………	235 51 13	
		11 12 0	……	……	………	235 50 54	180 28 25
Mons …………………	„ 4	4 12 5·8 P.M.	31 4·14	……	187 55 15		
		4 17 55·6	……	……	189 11 30		
		4 24 23·1	……	……	190 34 30		
		4 31 10·8	……	……	192 0 0		
		4 56 0	……	……	………	268 58 4·8	
		5 1 0	……	……	………	268 56 53·4	
		5 6 0	……	… ..	………	268 56 27·5	168 31 40

TABLE XIV. (continued).

Station.	Date.	Chronometer.	Error at Noon.	Daily Rate.	Azimuthal distance of sun from mark.	Azimuthal reading of magnet.	Azimuthal reading of mark.
	1871.	h m s	m s		° ′ ″	° ′ ″	° ′ ″
Tournay........................	Sept. 6	2 41 11·3 P.M.	+31 12·63	......	98 36 0		
		2 46 41·8	......	......	100 5 0		
		2 52 1·6	......	......	101 30 30		
		2 57 20·1	......	......	102 54 45		
		3 22 0	......	......	....	125 17 57·5	
		3 28 0	......	......	....	125 18 16·9	91 37 15
Courtray	„ 7	11 13 38·6 A.M.	31 16·88	......	96 9 45		
		11 18 59·0	......	......	97 56 30		
		11 25 2·8	......	......	99 59 0		
		11 30 57·5	......	......	102 0 30		
		12 3 30 P.M.	......	......	....	253 23 21·0	
		12 9 0	......	......	....	253 23 1·5	153 6 5
Ghent........................	„ 9	11 31 1·4 A.M.	31 25·37	......	28 50 30		
		11 42 56·0	......	......	24 46 30		
		11 51 58·1	......	......	21 39 30		
		12 9 0 P.M.	......	......	....	270 2 22·3	
		12 13 0	......	......	....	270 3 20·7	122 5 30
		1 27 0	......	......	....	269 53 23·9	
		1 31 30	......	......	....	269 52 44·0	122 6 30
Ostend	„ 12	8 58 23·4 A.M.	31 38·10	......	13 55 52		
		9 3 53·1	......	......	15 14 22		
		9 10 5·6	......	......	16 45 22		
		9 15 59·0	......	......	18 11 22		
		9 58 0	......	......	....	112 17 20·9	
		10 2 30	......	......	....	112 16 42·0	237 37 15
Bruges	„ 14	3 8 6·5 P.M.	31 46·69	......	19 17 45		
		3 17 18·4	......	......	21 34 0		
		3 26 49·9	......	......	23 52 0		
		4 0 30	......	......	....	186 1 46·6	
		4 5 30	......	......	....	186 1 40·1	237 12 5
Tronchiennes...............	„ 16	8 55 36·4 A.M.	31 55·08	......	58 44 30		
		9 1 37·8	......	......	60 10 15		
		9 6 41·1	......	......	61 23 30		
		9 10 51·1	......	......	62 24 0		
		9 50 30	......	......	....	192 31 21·4	
		9 57 0	......	......	....	192 30 24·2	
		10 1 0	......	......	....	192 31 42·1	94 1 10
Alost	„ 19	9 12 2·1	32 7·81	......	24 10 30		
		9 17 14·8	......	......	22 52 45		
		10 33 0	......	......	....	251 28 6·7	
		10 38 30	......	......	....	251 28 52·2	
		10 44 0	......	......	....	251 29 24·6	240 31 35
Brussels, 131 rue Royale	„ 20	2 12 39·5 P.M.	32 12·06	......	17 24 0		
		2 21 46·5	......	......	14 54 15		
		2 57 30	......	......	....	188 13 38·6	
		3 3 0	......	......	....	188 13 38·6	261 28 50
Brussels Observatory ...	„ 22	9 55 45·8 A.M.	32 20·55	......	32 42 45		
		10 0 56·0	......	......	31 18 15		
		10 51 30	......	......	....	181 57 24·2	
		10 58 30	......	......	....	181 55 14·4	192 25 0
	„ 22	11 13 44·4	......	......	10 17 45		
		11 19 11·5	......	......	8 35 15		
		11 49 30	......	......	....	181 42 30·6	
		11 54 0	......	......	....	181 40 46·8	192 47 37·5

To complete the determination of the Declination at the different stations, it is necessary to compute the azimuth of the sun at the times of observation. The mean result for each station is contained in the following Table, along with the Declination corrected for Scale-reading, as well as for Daily Range, and for any irregular perturbation that may have occurred at the moment of observation. Fortunately the magnet was always very quiet during the hours of observation, and hence the greater part of the correction in each case is due to Daily Range, which can be estimated more correctly than could the effect of any great disturbance. In order to calculate this correction, I have been obliged to make use of the magnetograms of Stonyhurst Observatory, as no continuous records have as yet been obtained in Belgium of the magnetic elements. The differences between the ordinates of the curve at the absolute times of observation, and the mean ordinate for July, August, September, and October, multiplied into 28′ 38″·9, the scale-coefficient of the Declination Magnetograph, give a close approximation to the correction required for reducing the results to September 1st for Stonyhurst. To apply these to observations made in Belgium I have introduced the factor 0·69, as I find from the mean values obtained at the Brussels Observatory for 9 A.M., noon, 3 P.M., and 9 P.M., compared with those deduced at Stonyhurst for the same hours, that the movements are in the ratio of 0·69 to 1. This will of course give only a first approximation, but the data will scarcely admit of greater exactness.

TABLE XV.

Station.	Azimuth of Sun.	Observed W. Declination.	Declination corrected for Range and Disturbance.
Antwerp	48° 9′ 41″·2	17° 30′ 41″·7	17° 33′ 16″
		17 30 22·2	17 31 33
Brussels Observatory	....	18 3 49·5	17 59 52
		18 4 46·0	18 1 0
Brussels, 131 rue Royale	76 2 47·7	17 8 0·4	17 12 45
		17 8 0·4	17 12 57
Louvain	47 49 41·1	16 46 15·3	16 50 12
		16 47 27·1	16 51 48
		16 49 49·9	16 55 10
Turnhout	22 4 5·1	17 13 13·7	17 5 32
		17 11 23·3	17 3 5
Liége	54 6 53·1	16 16 12·0	16 16 0
		16 17 3·9	16 17 16
Aix-la-Chapelle	72 21 10·3	16 30 51·2	16 28 29
		16 32 28·5	16 30 19
		16 34 38·3	16 32 39
Spa	17 5 47·9	16 43 44·9	16 39 59
		16 44 10·9	16 40 25
Arlon	45 8 52·8	16 29 35·4	16 23 51
		16 32 11·2	16 26 51
		16 33 42·0	16 28 34
Namur	10 10 14·0	17 40 36·0	17 34 52
		17 40 55·0	17 34 59
Mons	72 7 29·5	17 21 24·7	17 13 43
		17 22 36·1	17 15 41
		17 23 2·0	17 16 42
Tournay	49 15 37·1	17 50 14·2	17 43 43
		17 49 54·8	17 43 59
Courtray	18 47 53·8	17 54 32·8	17 47 14
		17 54 52·3	17 48 9
Ghent	11 1 26·5	17 59 4·3	17 54 8
		17 58 5·9	17 52 46
		17 59 3·5	17 49 58
		17 59 32·5	17 50 4
Ostend	56 45 19·0	18 6 57·6	18 7 34
		18 7 36·5	18 8 35
Bruges	54 43 41·9	18 1 11·5	17 58 25
		18 1 18·0	17 58 32
Tronchiennes	55 47 49·1	17 55 41·5	17 55 53
		17 56 38·6	17 53 53
		17 55 20·7	17 52 47
Alost	51 54 1·1	17 25 51·8	17 23 53
		17 25 6·4	17 22 44
		17 24 34·0	17 22 35
Brussels, 131 rue Royale	39 40 30·1	17 25 33·8	17 23 0
		17 25 33·8	17 23 12
Brussels Observatory	39 25 24·6	17 52 30·3	17 54 5
		17 54 40·1	17 56 15
” ”	16 25 10·1	18 3 46·9	18 3 47
		18 5 30·8	18 5 31

The figures in column 3, which are obtained directly from the unifilar, furnish the first members of the equations, whose solution is

$$\begin{aligned} x &= 0{\cdot}0119696, \\ y &= -0{\cdot}0012255, \\ \mathrm{D} &= 17^\circ{\cdot}3881. \end{aligned}$$

Thus the position of the isogonics will be N. 5° 50′ 46″·2 E. to S. 5° 50′ 46″·2 W., and the distance between lines, differing by 30′, 41·56 miles.

If, on the other hand, we use the corrected values of column 4 in the formation of our equations, the solution becomes

$$\begin{aligned} x &= 0{\cdot}0115492, \\ y &= -0{\cdot}0022202, \\ \mathrm{D} &= 17^\circ{\cdot}3368; \end{aligned}$$

and then the isogonics lie at an angle of 10° 52′ 54″·7 to the astronomical meridian, and their distance is 42·51 miles. The corrections have therefore altered very considerably the direction of the isogonics without affecting much their distance apart. We may judge from the following Table how far these corrections have diminished the probable error in the results.

TABLE XVI.

Station.	Uncorrected Declination.		Error.	Corrected Declination.		Error.
	Observed.	Computed.		Observed.	Computed.	
Aix-la-Chapelle......	0·544	0·483	+0·061	0·508	0·457	+0·051
Alost	1·420	1·567	−0·147	1·384	1·516	−0·132
Antwerp..............	1·509	1·402	+0·107	1·540	1·377	+0·163
Arlon	0·530	0·528	+0·002	0·440	0·424	+0·016
Bruges	2·021	2·014	+0·007	1·975	1·967	+0·008
Courtray	1·912	1·954	−0·042	1·795	1·880	−0·085
Ghent..................	1·983	1·740	+0·243	1·862	1·691	+0·171
Liége	0·277	0·732	−0·445	0·277	0·690	−0·413
Louvain...............	0·797	1·220	−0·423	0·873	1·178	−0·305
Mons	1·373	1·576	−0·203	1·256	1·490	−0·234
Namur	1·677	1·100	+0·577	1·582	1·032	+0·550
Ostend	2·121	2·173	−0·052	2·135	2·120	+0·015
Spa......................	0·733	0·577	+0·156	0·670	0·528	+0·142
Tournay..............	1·835	1·882	−0·047	1·731	1·796	−0·065
Tronchiennes.........	1·932	1·773	+0·159	1·903	1·723	+0·180
Turnhout	1·205	1·144	+0·061	1·072	1·125	−0·063

The probable errors at any station will therefore be ±0·16585 for the uncorrected and ±0·15234 for the corrected values, whilst those of the mean are respectively ±0·04146 and ±0·03809.

The direction of the isogonics, when the corrected numbers are employed, approaches nearer to that found for France than when the uncorrected observations are used, but it is still considerably in defect. There is scarcely any difference between the closeness of the lines in Belgium and in the West of France.

For the calculation of the secular variation of the Declination, the only available observations made out of Brussels are those of LAMONT in 1858, since the two observations of last century mentioned at the beginning of this paper would not help us to ascertain the actual yearly change of this element. Dr. LAMONT observed at Aix-la-Chapelle, Ghent, and Mechlin; but as I did not take the Declination at Mechlin, the comparison is confined to two stations.

TABLE XVII.

Station.	nation, Jan. 1, 1858.	Declination, Sept. 1, 1871.	Secular variation.
Aix-la-Chapelle	18·243	16·544	−0·124
Ghent............................	19·560	17·983	−0·115
		Mean for epoch 1864·8 ...	−0·1195

If we use the corrected values for September 1, 1871, the secular variation becomes −0·1255. LAMONT gives −0·1267 for 1858.

From the long series of observations made at the Royal Observatory of Brussels by MM. A. and E. QUETELET, from 1828 to 1871, I find the following values of the secular variation:—

Epoch	1838·75	−0·0896
,,	1849·5	−0·1065
,,	1860·25	−0·1234.

The yearly acceleration is therefore constant, and =−0·00158.

The observations at Brussels give very unsatisfactory results, when we regard the absolute values, and not merely the yearly change at a permanent unaltered station. In 1858 LAMONT found a difference of 28′ between the Declination at the observatory and that at a station not far distant; E. QUETELET confirmed this result the same year, the difference being 30′; and now, at positions so close together as the observatory and 131 rue Royale, I find a still greater mean difference. The Declination observations made at Brussels during this survey were as follows:—

	Uncorrected values.	Corrected values.
Computed results	17°·3881	17°·3368
Observatory, August	18·0716	18·0072
,, September . . .	17·8931	17·9195
,, ,, ...	18·0775	18·0775
,, Error of mean .	+ 0·6260	+ 0·6646
131 rue Royale, August . . .	17·1334	17·2125
,, September . .	17·4261	17·3850
,, Error of mean	− 0·1083	− 0·0380

The station near the observatory, though apparently not free from disturbing influences, gives from the corrected values a result almost identical with the computed quantity, since it is within the range of its probable error, whilst the result for the observatory itself is more than half a degree in excess. This difference of Declination, combined with the fact that the errors of the observed Dip at both stations are positive and their errors of H. F. both negative, might justify the assumption that the disturbing cause is situated at no great distance from the observatory, and probably at some depth and to the W. of the N. meridian. The probable errors of the observed Dip and H. F. at the observatory were not very large, being respectively $+7' 15''$ and $-0{\cdot}0070$.

It may be of advantage, in particular for the discussion of the errors of the Total Force, to present here in a tabular form a geological description of the stations of observation. The data in this Table are taken from the excellent map of M. André Dumont, a copy of which was kindly presented to me for this purpose by his son.

TABLE XVIII.

Station.	Geological formation.
Aix-la-Chapelle	Terrain crétacé, système Aachenien. E.S.E. houille.
Alost	Terrain tertiaire, eocène, glauconie.
Antwerp	,, ,, pliocène, système Scaldisien.
Arlon	,, jurassique, système liasique.
Bruges	,, tertiaire, miocène, argile verte et sable marin.
	,, ,, eocène, glauconie supérieure.
Brussels	,, ,, ,, glauconie; sable et grés de Beauchamp.
Courtray	,, ,, ,, glauconie moyenne.
Ghent	,, ,, ,, glauconie supérieure.
Liége	E., W., N. houille. S. terrain anthraxifère, système Eifelien, quartzoschisteux.
Lierre	Terrain tertiaire, pliocène, système Diestien.
Louvain	,, ,, N. miocène, argile verte et sable marin; S. glauconie supérieure; E., W. pliocène, système Diestien.
Mechlin	,, ,, miocène, argile verte, sable marin, et grès de Fontainebleau.
Mons	E., N.E., S.W. houille. S. terrain tertiaire, eocène, glauconie moyenne.
Namur	Terrain anthraxifère. N. système Condrusien, calcareux; S. houille.
Ostend	Alluvions.
Spa	Terrain Ardennais. N.W. terrain Rhénan, système Gedinnien.
Tournay	,, tertiaire, eocène, glauconie. S.E. terrain anthraxifère, système Condrusien, calcareux.
Tronchiennes	Terrain tertiaire, eocène, glauconie supérieure.
Turnhout	,, ,, miocène, système Bolderien.
Verviers	,, Ardennais, système Salmien; et terrain Rhénan, système Gedinnien.

The three maps annexed to this paper (Plates XIX.–XXI.) show the general direction of the lines of equal Dip, H. F., and Declination. The broken lines for 1871 are calculated on the supposition of the isoclinals, isodynamics, and isogonics being approximately straight, and the observed mean values are attached to each station in order to show how nearly these straight lines represent the actual curves.

This has also been made more evident by introducing the curves of equal values, which are represented by continuous lines. The method adopted in drawing these lines is shown in the map of the isodynamics; and the shaded portions of the same map indicate the position and extent of the coal-beds of Belgium, which lie, for the most part, along the banks of the Meuse.

The greatness of the accidental errors, as well as the narrow limits of the tract of country under consideration, renders it very difficult to trace, with any great degree of accuracy, the probable curvature of the actual lines of equal Dip, Declination, and Intensity. But bearing in mind that in all cases the errors arising from defects of station or of observation mask to a great extent the real nature of these curves, we may still clearly perceive two apparent centres of disturbing action,—the one situated in the N.W. centre, and manifested by a great increase of the Dip and a diminution of the Horizontal Force, and the other, more extended and less intense, stretching along the Coal-measures, and giving evidence of its existence by a diminution of the Dip and an increase of the Horizontal component of the Intensity.

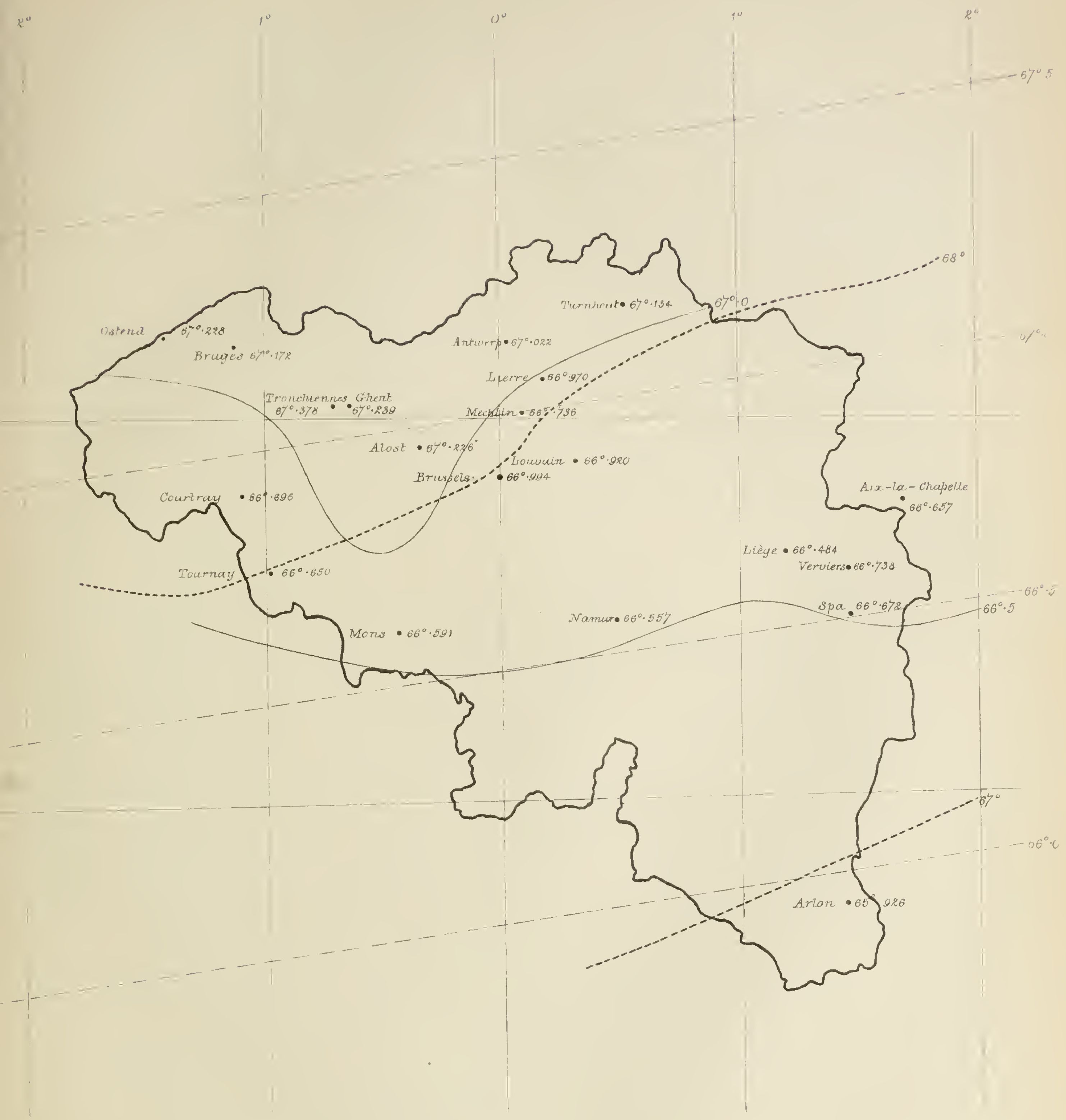
The dotted lines are an enlarged reproduction of the curves on LAMONT'S maps; and from being enlarged they will naturally give a somewhat exaggerated idea of the lesser inequalities, though the general curvature be perfectly correct.

I will now conclude this paper with a list of the magnetic elements at the several stations, the observations being all reduced to the common epoch, January 1st, 1872. In this reduction I have adopted the yearly changes determined by the survey, viz. $-0{\cdot}0573$, $+0{\cdot}00542$, $-0{\cdot}01155$, and $-0{\cdot}1255$ respectively for the Dip, H. F., T. F., and the corrected Declination.

TABLE XIX.

Station.	Declination.	Dip.	Horizontal Force.	Total Force.
Aix-la-Chapelle	16°·464	66°·637	4·0064	10·1025
Alost	17·349	67·210	3·9518	10·2016
Antwerp	17·489	66·999	3·9296	10·0559
Arlon	16·398	65·907	4·1175	10·0857
Bruges	17·938	67·155	3·8950	10·0321
Brussels	17·959	66·975	3·9613	10·1271
Courtray	17·756	66·678	4·0028	10·1103
Ghent	17·823	67·221	3·9197	10·1232
Liége	16·233	66·464	4·0145	10·0522
Lierre	....	66·948	....	....
Louvain	16·824	66·898	3·9565	10·0828
Mechlin	....	66·714	....	....
Mons	17·216	66·573	4·0065	10·0767
Namur	17·541	66·538	3·9941	10·0311
Ostend	18·097	67·211	3·9152	10·1077
Spa	16·627	66·653	4·0239	10·1531
Tournay	17·691	66·632	3·9975	10·0776
Tronchiennes	17·867	67·361	3·9032	10·1397
Turnhout	17·025	67·113	3·9542	10·1665
Verviers	....	66·718	....	....

Magnetic Dip.



Isoclinals Epoch 1871 — - - - - - - —

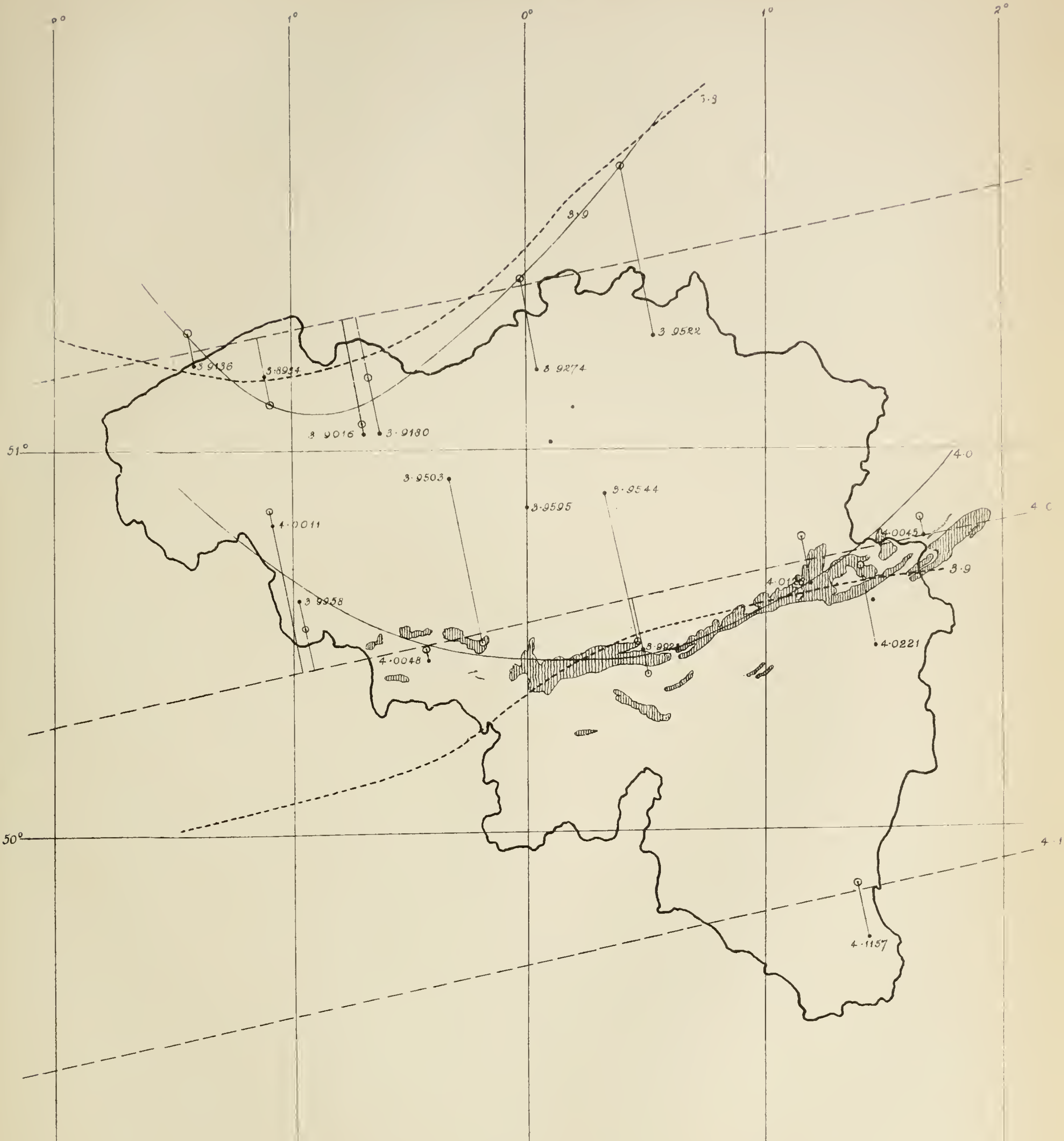
" " 1849 - - - - - - - - - - - - - - - -

W.E. Wesley lith.

W. West & Co imp.

LIBR
OF THE
UNIVERSITY of ILLINOI

Magnetic Intensity.



Lines of equal Horizontal Force. Epoch 1850 - - - - - - - - - - - - - - - -

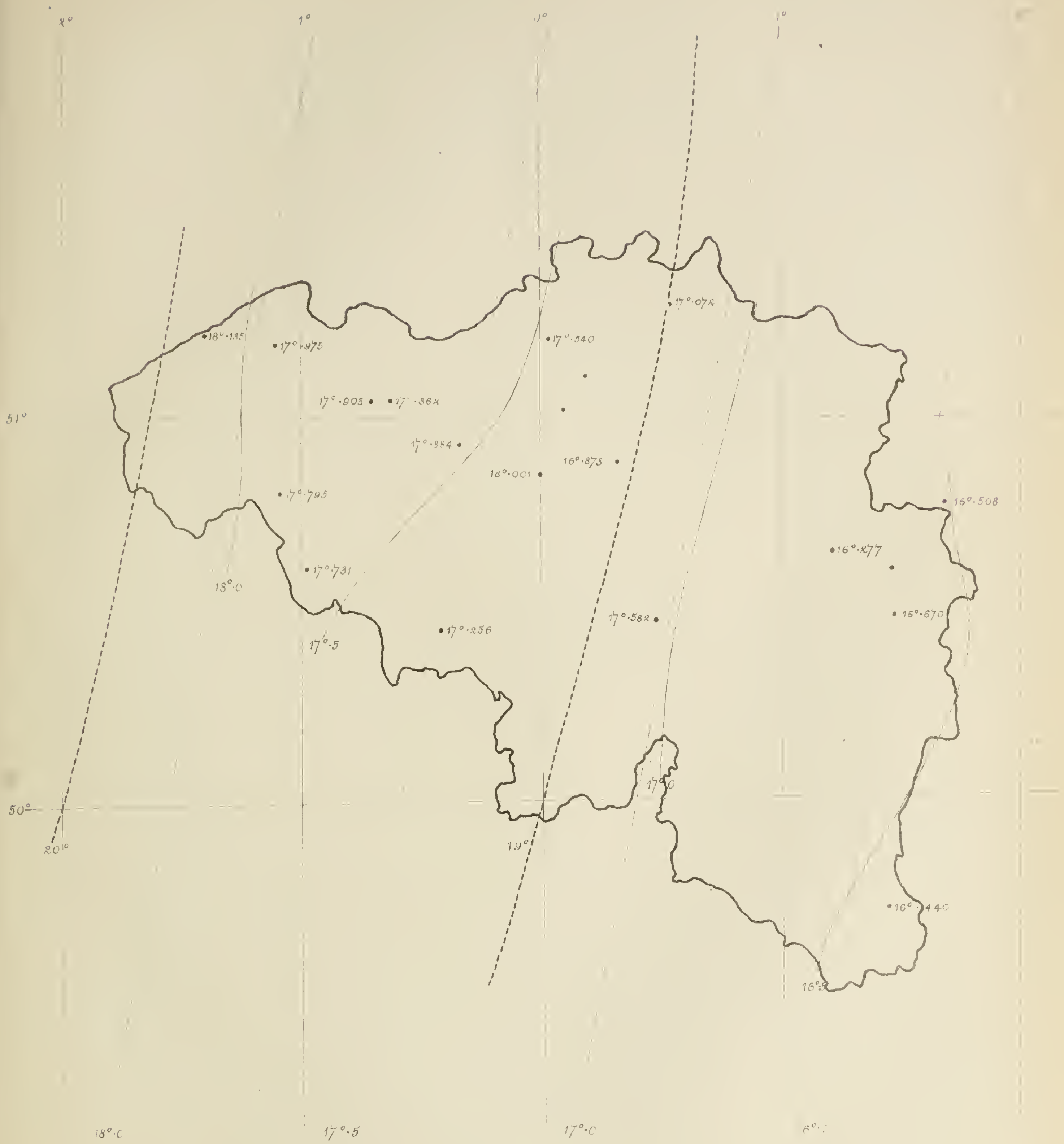
" " 1871 — — — — — — — —

W H Wesley lith

W West & Co imp

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

Magnetic Declination



Isogonics Epoch [illegible] ------------------------

" " 18[illegible] - - - - - - -

W.H. Wesley lith.

W. West & Co. imp.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

IX. *On the Union of Ammonia Nitrate with Ammonia.* *By* EDWARD DIVERS, *M.D.* *Communicated by Professor* ODLING, *M.B., F.R.S.*

Received October 29, 1872,—Read January 9, 1873.

1. AMMONIA nitrate possesses the somewhat remarkable property of combining with large quantities of ammonia. The product is a liquid the composition of which varies with the temperature and pressure to which it is subjected. It appears from its properties to be a solution of ammonia nitrate in liquefied ammonia, analogous in every respect to an aqueous solution of a salt, its formation being a phenomenon precisely like that of the deliquescence of a salt in a moist atmosphere.

2. The liquid was prepared by bringing dry ammonia gas into contact with dry ammonia nitrate in a flask loosely closed by a vulcanized caoutchouc stopper (to diminish loss of ammonia by diffusion) and imbedded in ice. The tube conveying the ammonia passed through the stopper and reached nearly to the bottom of the flask.

Care was taken to ensure as much as possible the absence of moisture. The nitrate was dried either by leaving it for a month or more spread out in crushed crystals on the floor of an air-tight glass chamber, in which were placed dishes of oil of vitriol, or by exposing it for some hours in an oven to a temperature only a little below its melting-point*. The nitrate was put into the dry and warm flask with as little exposure as possible, by scooping it up rapidly with the mouth of the flask direct from the vessel in which it had been dried. The flask was then at once closed and kept so until all arrangements were complete for passing the ammonia into it. The ammonia was dried by sending it through a glass tube more than 50 centimetres long, closely packed with very small pieces of stick potash; but before entering this tube it was deprived of most of its moisture by being made to pass through a long coiled tube surrounded with ice and thus cooled.

3. The condensation of the ammonia by the nitrate takes place slowly at ordinary temperatures, and in the cooled flask is complete until the point of saturation with ammonia is approached. The nitrate soon shows signs of deliquescence in the ammonia, and, after awhile, entirely liquefies. The resulting liquid still, however, possesses the power of condensing ammonia, and that to a considerable extent; while, on the other hand, the liquid saturated with ammonia can dissolve an additional quantity of ammonia nitrate. Raising the temperature of the liquid, loss of ammonia being

---

* As the latter proved a less certain method of obtaining the nitrate quite dry, in consequence apparently of slight decomposition of the nitrate, the former only was employed in preparing the specimens of the liquid intended for the determination of its physical properties.

prevented, increases its capability of dissolving more nitrate, and lessens that of condensing more ammonia. On cooling the liquid, saturated or nearly so with nitrate, some of the salt crystallizes out in long prisms, exactly like those that form in an aqueous solution; on restoring the temperature these crystals redissolve. When the liquid is warmed, it gives off ammonia gas with the phenomenon of ebullition, not that of effervescence. Like many aqueous solutions, the liquid can be heated a little above its boiling-point without boiling, and be cooled below its crystallizing point without crystallizing, until it is disturbed, when ebullition or crystallization, as the case may be, takes place with suddenness. On boiling away the ammonia, or expelling it at a temperature below that of ebullition, the nitrate crystallizes out, just as it would do in similar circumstances from its aqueous solution. When the liquid is exposed to the air it instantly becomes crusted over with a film of nitrate, which is coherent, transparent, and apparently not crystalline. In consequence of this the liquid poured out on to a flat surface, sometimes even in the act of flowing from the mouth of the bottle, takes the appearance, though not the consistence, of jelly. On touching this apparent jelly, unchanged liquid breaks through the crust; and by stirring the mass about in a dry atmosphere, nothing but solid ammonia nitrate at length remains. When the crust is not broken, it preserves the enclosed liquid for a long time from further evaporation in dry weather.

The liquid is colourless, and as mobile as any aqueous saline solution. It smells very powerfully of ammonia, unless it be allowed to crust over, when this smell is almost wanting. It has not a slimy feel between the fingers like an alkali lye, and seems, indeed, to have no caustic power. It boils when poured on the skin, and gives rise to a slight feeling of crepitation, but it produces only a feeble sensation of cold.

4. The quantity of ammonia that can be condensed by the nitrate varies with the pressure and temperature, and appears to be quite independent of the atomic relations of the two substances. At the pressure of the atmosphere and at a temperature of 0°, ammonia nitrate can condense almost exactly half its weight of ammonia. Its condensing-power, therefore, exceeds that of water at the same temperature. The ratio of two parts nitrate to one of ammonia is about that of $3NO_3H \cdot NH_3 : 7NH_3$; but there is nothing to support the view that the liquid is a definite molecular combination.

To determine the limit just stated of the condensing-power of the nitrate upon ammonia gas, at 0° and the atmospheric pressure, the closed flask containing the nitrate was weighed, and from the weight found was deducted that of the empty flask, its stopper, and an iron wire that served both to suspend the flask to the balance and also afterwards to bind down the stopper. The flask generally employed was one adapted for taking the specific gravity of the liquid, and which shall be more particularly described in connexion with that operation. The quantity of nitrate employed weighed from 35 to 45 grains. When the ammonia had been passed into the flask, surrounded with ice, for some time after absorption had apparently ceased, the delivery-tube was withdrawn, the flask at once closed, and the stopper wired down. The flask was then removed from the ice, left to regain the atmospheric temperature, and again weighed. The delivery-tube on removal from the flask was washed, the washings were evaporated, and the nitrate left as residue weighed. By deducting the weight of this nitrate from that of the whole quantity put into the flask, the weight of this salt in the liquid was ascertained; and by deducting this from that of the liquid, the weight of the ammonia condensed was obtained.

The smallest quantity of ammonia sufficient to liquefy the nitrate at 0° is a little more than one third of its weight. This point was determined by boiling away some ammonia from the liquid containing more than sufficient of it, until on cooling to 0° the liquid just began to crystallize. This method, for several reasons, is not a very accurate one for the purpose, one reason being that the liquid is apt to exhibit to some extent, as already stated, the phenomenon of supersaturation; but it was employed for want of a better, that would not have entailed trouble disproportionate to the importance of an accurate determination of this point at present.

At 23°, the temperature at about which the nitrate and ammonia cease to unite at the atmospheric pressure, the ratio of the quantities that form the liquid is that of 100 nitrate to 26 ammonia. This ratio was determined by first condensing, under the guidance of some previous experiments, about 27 parts of ammonia upon 100 of nitrate in the flask, dissolving up the whole of the nitrate by warming and agitating the contents of the closed flask, and then loosening the stopper and cautiously allowing the ammonia to boil off until on cooling the liquid to 20° the nitrate began to crystallize out. The stopper was then closely inserted again, and the temperature raised very slowly by means of a water-bath until the nitrate, by continued agitation, had all redissolved, save a very minute crystal. The temperature required to effect this resolution exceeded 28°. On now allowing the flask to cool very slowly in the (glass) water-bath and watching the crystal, it was not observed to show any increase in size until the temperature had fallen to 22°·5, when its enlargement became distinct. The liquid was therefore regarded as saturated with nitrate at 23°. It was also about saturated with ammonia, because beyond this temperature ammonia ceases to be condensed by the nitrate at the atmospheric pressure, and to this the liquid had been exposed. By now ascertaining the weight of the liquid and deducting that of the nitrate, the above ratio was obtained.

5. In the conjoint liquefaction of ammonia nitrate and ammonia heat must be consumed by the nitrate in passing from the solid to the liquid state, and be generated by the ammonia in passing from the gaseous to the liquid state. The heat produced by the latter change proves to be in excess of that consumed by the former, even when, by keeping the nitrate in excess, the greatest relative liquefaction of this salt is ensured; that is to say, the formation of the liquid is always attended with the evolution of heat. On the other hand, as already described, the destruction of the compound is attended with the production of cold.

As was stated in the previous section, the temperature above which ammonia nitrate and ammonia cease to unite is about 23°–24°; for on bringing these bodies in contact at a temperature *below* 23°, this soon rises to that of 23°–24° (the temperature evidently varying with the atmospheric pressure) and remains at this point, even (after some liquefaction has taken place) when the ammonia, before it comes in contact with the nitrate, is heated several degrees *above* 23°, the result in this case being, without doubt, due to the destruction that then takes place of the liquid already formed.

The boiling-point of the liquid, when saturated with nitrate at 23°, was found to be about 26°; but as the liquid boils irregularly, it is very probable that the true boiling-point lies a few degrees below this.

6. For the purpose of taking the specific gravities of the products obtained by using different proportions of ammonia and nitrate, a flask was employed having a long graduated neck. Different quantities of nitrate were weighed in it, and then into each quantity ammonia gas was passed until the resulting liquid filled it at 15°·5 to some point in the neck. The body of the flask was globular, had stout walls, and contained nearly 46 cubic centimetres. The neck consisted of a piece of barometer-tube, surmounted by a larger tube, into which it abruptly expanded. This part of the neck served as a funnel, and also to receive any of the liquid carried by the bubbles of ammonia above the top of the narrow tube. It was made without everted lip, so as to facilitate the scooping up of the nitrate by it. The shoulder it formed with the narrow part of the neck served to retain the wire used to bind down the caoutchouc stopper. The narrow, graduated part of the neck was about 7 centimetres long, and had an internal diameter of about 6½ millimetres. The weight of water at 15°·5 held by the flask to the level of every twentieth graduation, of which there were sixty-five, was experimentally determined; intermediate quantities were calculated. The delivery-tube for the ammonia was a slender one, in order that it might leave as much room as possible in the neck for the rise of bubbles through the liquid; but even with this arrangement the liquid sometimes rose into the funnel, and did not always satisfactorily drain down again.

The following specific gravities were taken:—

No.	Ammonia nitrate.	Ammonia.	Specific gravity.
1. . . .	1000 parts.	495·5 parts.	1072·5
2. . . .	1000 ,,	392·5 ,,	1119·95
3. . . .	1000 ,,	385 ,,	1126·05
4. . . .	1000 ,,	334 ,,	1155·9
5. . . .	1000 ,,	316·5 ,,	1167·05
6. . . .	1000 ,,	281·5 ,,	1191·65
7. . . .	1000 ,,	272 ,,	1199

(The liquid No. 7 crystallized when cooled to the standard temperature, so that its specific gravity had to be taken at a higher one, and from this its specific gravity at

15°·5 calculated by means of its approximate coefficient of dilatation, which was determined by other observations.)

By taking the numbers expressing the specific gravity and composition of Nos. 1 & 6, it is easy to compute the specific gravity of the excess of the ammonia in No. 1 over that in No. 6, on the assumption that the latter liquid undergoes no change in density by uniting with more ammonia. On making the further assumption that all the ammonia condensed by the nitrate has the same density, the specific gravity of the nitrate in the liquid can also be calculated; or this can be found directly for the excess of the nitrate in No. 6 over that in No. 1 in union with the same weight of ammonia, in the same way as that for the ammonia was calculated. On then calculating from the weights of the two substances, and the specific gravities thus found for them, the specific gravities of the liquids the composition of which is given in the preceding Table, the assumption that the densities of the two substances are constant is found to be correct, in so far, that is, as the results are concerned. The calculated specific gravity of the ammonia is 671, and that of the nitrate 1524·5. The specific gravities of the liquids calculated from these numbers are placed in the following Table by the side of those found by experiment, and their almost entire identity within the limits of experimental error thus rendered apparent:—

No.	Calculated.	Found.
1.	1072·5	1072·5
2.	1122·0	1119·95
3.	1126·3	1126·05
4.	1156·1.	1155·9
5.	1167·35	1167·05
6.	1191·45	1191·65
7.	1198·55	1199·0

Except in the case of No. 2 the differences between the two series of numbers are quite within the limits of experimental error, and in that case some unobserved error no doubt must have been made in the determination.

The calculated specific gravity of the ammonia in these liquids (671) is greater than that found for ammonia liquefied by pressure by ANDRÉEFF* (615·5 at 15°·5) or by JOLLY† (623·4 at 0°). GRIFFIN‡ has calculated the specific gravity of ammonia liquefied by water to be constantly 708, on the usual assumption that the density of the water is constant, a number not far from that found by FARADAY§ (731) for ammonia liquefied by pressure. The calculated specific gravity of the nitrate in the liquid (1524·5) is much less than the number (1740) found for the solid nitrate by KARSTEN‖, that by KOPP¶ (1707), or that by PLAYFAIR and JOULE** (1635); it is also much less than the calculated specific gravity of the nitrate in dilute aqueous solution, namely 1758, according to PLAYFAIR and JOULE. But the observations of THOMSEN[*] show that the specific gravity of the nitrate appears to vary from about the number obtained by PLAYFAIR and JOULE to that of 1565·5 at 18°, in a solution of 8 of nitrate in 9 of water; and I have myself found it to have in a solution of 12 nitrate in 7 water an apparent specific gravity of 1572·5 at 15°·5, a number not greatly exceeding that expressing its apparent density when liquefied by ammonia. The ammonia and the nitrate in the liquid have therefore each a less apparent density than they have when dissolved in water, and the nitrate a much less apparent density than its actual density in the solid state.

---

* Ann. Chim. Phys. [3] lvi. p. 317.

† Ann. Ch. Pharm. cxvii. p. 181.

‡ Mem. Chem. Soc. iii. p. 155.

§ Phil. Trans. (1845) p. 169.

‖ Ber. Abhandl. (1840) p. 95.

¶ Ann. Ch. Pharm. xxxvi. (1840) p. 1.

** Mem. Chem. Soc. ii. p. 436.

7. The flask used for determining the specific gravity served also for some rough determinations of the expansivity by heat of the liquids of different composition. By observing the height of the liquid at 0°, and again at 15°·5, the expansion between these temperatures was ascertained, and from this the expansion between 0° and 100° calculated, on the assumption that the expansion proceeds uniformly. The results obtained were the following:—

No.	Ammonia nitrate.	Ammonia.	Expansion from 0° to 100°.
1.	1000	495·5	about $\frac{1}{16}$
2.	1000	392·5	" $\frac{1}{17-}$
3.	1000	385	" $\frac{1}{17+}$
4.	1000	334	" $\frac{1}{17+}$
5.	1000	316·5	" $\frac{1}{18-}$

They are sufficient to prove that the expansivity of the liquid increases with the ratio of the ammonia to the nitrate; they also show that the expansivity of ammonia liquefied in this way is similar to that of other liquids existing as such under the pressure of the atmosphere, and far less than that of ammonia and other substances kept in the liquid state only by great pressure. Thus, from the experiments of ANDRÉEFF[†], it appears that ammonia liquefied by pressure expands nearly $\frac{1}{22}$ of its volume when its temperature is raised from 0° to only 20°.

8. The volume of a mixture of the liquid with water is much less than the sum of the volumes of the liquid and the water used; and yet the admixture is attended with a considerable absorption of heat. The same remarkable phenomenon is manifested when a concentrated aqueous solution of the nitrate is mixed with water, and, indeed, by concentrated aqueous solutions of other salts, though, I believe, not by any of them to the extent that it is by that of the nitrate in either water or liquefied ammonia. PERSON[‡] calls the heat that thus disappears the *latent heat of dilution.*

When the liquid of specific gravity of 1191·65 (No. 6 in the preceding Tables), and composed of 1000 nitrate to 281·5 ammonia, was mixed with five times as much water as the weight of the nitrate in it, the admixture was attended with a fall of 4° C. in the liquids both at first at the temperature of the laboratory. In effecting the admixture, the closed flask containing the liquid was inverted, with its mouth below the surface of the required quantity of water, and maintained there by a wooden holder; the wire retaining the stopper was then cut, and the latter removed by means of a pair of tongs. The liquid rapidly descended into the water and was replaced by the latter, which in its turn was replaced by air, by bringing the mouth of the flask just above the surface of the liquids. These were then at once briskly stirred round with a thermometer, and the altered temperature noted, the entire operation of mixing having occupied but a very short time. A specific-gravity bottle was immediately afterwards filled with the mixture, so that no appreciable loss of ammonia could have been sustained, the more so that the experiments were made in winter. Lastly, its specific gravity was taken at the standard temperature and found to be 1043·8. By assuming that the water undergoes no change in density, the specific gravity of the liquid after its admixture with the water can be calculated, and proves to be 1258·6 instead of 1191·6, its original specific gravity.

---

[*] POGG. Ann. cxlii. p. 337.

[†] Ann. Chim. Phys. [3] lvi. p. 317.

[‡] Ann. Chim. Phys. [3] xxxiii. p. 448.

When a solution of 12 parts of nitrate in 7 of water, which is an almost saturated one at 15°·5, is mixed with 5 times 12 or 60 parts of water, there is also a fall in temperature of 4°, accompanied by condensation*: for before admixture the specific gravity of the primary solution is 1298·7, while afterwards its specific gravity, calculated from that of the mixture, 1064·4, is 1336; whence it will be seen that the contraction in volume, though very considerable, is not so great as that experienced by the ammonia solution of the nitrate, as might indeed be anticipated from the fact that the calculated densities of the nitrate and the liquefied ammonia are both less than their densities in aqueous solution.

When the liquid (No. 1 in the preceding Tables) containing the least proportion of nitrate, namely two thirds of its weight, was mixed with water in the proportion (for the sake of comparison) of five parts to one of the nitrate, the temperature was found to fall only about $\frac{1}{4}$°. The admixture was effected as before, except that on removing the stopper the liquid was in this case violently expelled from the flask into the water by some ammonia becoming gaseous, and that then the water rose into the flask by absorbing this gas. The specific gravity of the mixture was found to be 1026·4, and from this was calculated that of the liquid after its admixture with water. Instead of its original specific gravity, which was 1072·5, it had in the mixture that of 1125·8. Compounds of the nitrate with ammonia in other proportions were also mixed with water, and results obtained confirming those just detailed. The proportion of five parts water to one of the nitrate was chosen for the comparative experiments in order to have the mixture dilute, and therefore less liable to lose ammonia by diffusion; with less water a greater depression of temperature would no doubt have been observed, but the investigation was not further pursued in this direction.

The small extent of the fall in temperature when the liquid containing the least proportion of nitrate is mixed with water, is to be attributed principally to the fact of the nitrate being in more dilute solution than in the other case described; for it is found on diluting a concentrated aqueous solution that the cold is produced in the earlier stages of the dilution. It is perhaps also to be attributed, to a slight extent, to the presence of more ammonia than in the other cases; since it is possible that ammonia in the liquefied condition may generate a little heat when mixed with water, and this must mask the cold produced by the nitrate to a corresponding extent.

---

* Gay-Lussac first observed the fall in temperature with contraction in volume that occurs when a concentrated solution of ammonia nitrate is diluted with water (Ann. Chim. Phys. i. p. 214).

The accompaniment of contraction of volume by absorption of heat, here illustrated, has received several explanations. GAY-LUSSAC, in accounting for it, considered that the specific heat of the mixture must be greater than the mean of the specific heats of the saline solution and the water; but THOMSEN'S[*] researches have shown that the specific heat of a mixture of an aqueous solution and water is *less* than the mean of the specific heats of the solution and water. THOMSEN has also pointed out that where (as in the case of the salts of the fixed alkalies) the molecular volume is greater than the sum of those of its constituents, the molecular heat of the compound is greater, and that, on the other hand, where (as in the case of ammonia salts) the molecular volume is less, the molecular heat is also less; so that it appears that volume and specific heat lessen and increase together.

Another explanation is one that has been offered by BUSSY and BUIGUET[†], whose attention was drawn to this subject by their observation of the simultaneous contraction in volume and absorption of heat that occurs when liquid hydrocyanic acid and water are mixed together, and who have established that no apparent relation exists in these cases between changes in volume and changes in temperature. They ascribe the production of cold to the diffusion of the one liquid through the other, by which, according to their notions, each occupies a greater volume than it did before. But although after admixture each liquid does extend through a greater space, it does not do so by undergoing an increase in volume, but by being displaced by the other liquid, the space occupied by the mixture being filled up by the two liquids conjointly—assuming, that is (as is necessary in applying the above explanation), that the two liquids preserve their individuality during admixture. Now, unless diffusion involves expansion, it is hardly evident how it can afford any solution of the difficulty.

F. MOHR[‡] has suggested that the heat which disappears is the excess of that used up in giving to the mixture the property of remaining liquid at a lower temperature than water itself can, over that evolved in giving it the property of remaining liquid at a higher temperature than the water. This is apparently to assume that the latent heat of water is variable and inversely related to the temperature of freezing, just as the latent heat of steam is variable and inversely related to the temperature at which it is formed; and the assumption seems probable enough.

The anomaly that presents itself, when the density of the water is considered to remain constant during the dissolution of a salt in it, of the nitrate having in concentrated solutions a greater, and in dilute solutions a less volume than it has in the solid state, disappears by supposing that while the salt always undergoes during solution the contraction in volume so evident when the proportion of water is large, the water undergoes slight dilatation: for then it follows that when the salt is dissolved in only a small quantity of water, the former will experience a less contraction and the water a greater expansion, and that thus there may be a total increase in volume; while when the salt is dissolved in a large quantity of water, the contraction of the salt will be in marked excess of the expansion of the water, and therefore will become evident in the increase in total volume. Dilute solutions of sodium carbonate and of some sulphates, having a less volume than the total water they contain, appear to afford an argument against the above supposition; but in these solutions the salts dissolved are not the anhydrous ones, but those with water of crystallization.

---

[*] POGG. Ann. cxlii. p. 337; Chem. Soc. Journ. [2] ix. p. 468.

[†] Ann. Chim. Phys. [4] iv. p. 5.

[‡] Deut. Chem. Ges. Ber. iv. p. 314.

By dissolving ammonia nitrate in concentrated ammonia-water, the latter is affected in the same way as it would be by dilution with water, so far, that is, as the tension of the ammonia diffusing from its surface is concerned.

9. The chemical behaviour of the liquid, like its physical properties, tends strongly to show that it is simply a solution of ammonia nitrate in liquefied ammonia. As a solvent, it appears, from the brief abstract as yet published of Mr. GORE's experiments*, to resemble ammonia liquefied by pressure. But the ammonia nitrate modifies the solvent action of the ammonia in the same way that it does that of ammonia in aqueous solution. Its chemical properties are interesting, but in most instances such as might be expected in a mixture of ammonia nitrate and ammonia *in the absence of water*. The general effect of the liquid upon salts appears to be to convert them into ammoniated nitrates and ammonium salts of the stylous radicals.

As, however, a quantitative examination of the products would be attended with considerable difficulties from the nature of the liquid and the decomposition of the products by water, only a qualitative one has been attempted.

Bromine acts very energetically on the liquid, instantly dissolving in it without colour and liberating nitrogen. Ammonia hydrobromide is formed, and much of it deposited. No bromate is produced.

Chlorine has not been tried.

Iodine dissolves slowly, but to a considerable extent, in the liquid, with evolution of heat. No gas is generated. A very little of the iodine dissolves without imparting any colour, but the after portions colour it until it becomes of a rich, deep brown-red, and almost opaque. Very early during the dissolution of the iodine a crystalline deposit, apparently white, begins to form, and this continues to be produced until it renders the whole nearly solid. No diniodamine is formed. The iodine seems, therefore, to dissolve in the liquid either simply or in the form of MILLON's compound—$N_2H_6I_2$*. Treated with water it yields nitrate and a little hydriodide in solution, and a deposit of iodine containing some iodamine. Immediately the magma is exposed to the air, it takes the colour and metallic lustre of iodine (like MILLON'S compound), evidently from the escape of ammonia and deposition of iodine. Heated in a water-bath ammonia escapes, and in a little while iodine vapours along with it. The residual mass, apparently a mixture of ammoniacal salts and free iodine, gives up quantities of the latter to carbon bisulphide, and, by the application of a somewhat higher temperature, continues to give it off in vapour for some time. It then consists of ammonia nitrate and hydriodide, the latter in rather considerable quantity. As no iodate is formed, nitrogen must escape during the exposure of the mass to heat, in accordance with MILLON'S observations upon iodine and ammonia.

---

* Proc. Roy. Soc. xx. p. 441.

† Ann. Chim. Phys. lxix. p. 78.

Phosphorus is very slowly stained throughout its mass of a brown colour, and a minute quantity of brown flocculent matter forms upon its surface, which is apparently unaffected by hydrochloric acid. After neutralization, the liquid smells of phosphoretted hydrogen, but no appreciable quantity of phosphorus is dissolved in it. (According to COMMAILLE *, alcoholic ammonia gradually turns phosphorus brown, ammonia phosphite and hypophosphite being at the same time formed.)

Potassium, *sodium*, *zinc*, and *cadmium* dissolve without the evolution of gas, and convert the nitrate into nitrite. The alkali metals act with much the same energy that they do upon water, melting and rolling about on the surface of the liquid till dissolved, the potassium always inflaming: the nature of their action is best ascertained by using dilute amalgams of them. The dissolution of the zinc is soon accompanied by the deposition of a bulky crystalline matter, apparently an ammoniated zinc nitrate. Cadmium dissolves only slowly. (Free ammonia so greatly intensifies the action of zinc and cadmium upon an aqueous solution of a nitrate, that STAHLSCHMIDT† prepares nitrites in this way.)

Magnesium is slowly dissolved with the evolution of hydrogen and the formation of nitrite. The surface of the metal becomes covered with a black deposit, which immediately turns white on contact with the air. This black matter is probably the suboxide of magnesium, which was observed by BEETZ‡ to be formed when a solution of salt was electrolyzed with magnesium electrodes.

Hydrogen, *nitrogen*, *oxygen*, *carbon*, *sulphur*, *iron*, *aluminium*, *nickel*, *tin*, *lead*, *bismuth*, *copper*, *mercury*, *silver*, and *platinum* are unaffected. Traces of lead and bismuth are found in the liquid, but probably these are dissolved oxides. Copper in the presence of air dissolves as it does in aqueous ammonia, but less readily.

Ammonia hydrochloride slowly dissolves to a moderate extent. Most chlorides are either dissolved or converted into ammonia hydrochloride and an insoluble or nearly insoluble ammoniated compound.

Potassium chloride is sparingly soluble.

Sodium chloride cakes together, and only dissolves to a slight extent.

---

* J. Pharm. Chem. [4] xiv. p. 184.

† POGG. Ann. cxxviii. p. 466; Suppl. Watts's Dict. Chem.

‡ POGG. Ann. cxxvii. p. 45.

Silver chloride and *barium chloride*[*] slowly dissolve to a moderate extent.

Lead chloride dissolves freely. The solution may be mixed with several times its volume of water before precipitation begins to take place.

Calcium chloride and *cupric chloride* also dissolve freely, but the dissolution is at length attended with deposition of crystalline matter. The cupric solution is of the usual deep blue colour.

Magnesium chloride, zinc chloride, and *cuprous chloride* dissolve to a moderate extent, any excess that may be present being converted into white, bulky, crystalline deposits, soluble in water. The cuprous deposit and solution rapidly turn blue on exposure to the air.

Mercuric chloride dissolves sparingly. Water does not throw down any thing when added to the solution, white precipitate being soluble in ammonia nitrate (Brett).

Mercurous chloride is decomposed into metallic mercury (a grey precipitate assuming the form of globules when washed and dried) and ammoniated mercuric salt, which dissolves.

Nickel chloride (bright yellow) becomes a bulky lilac-coloured mass, with slight evolution of heat. The liquid remains colourless, and takes up no nickel compound, but much (ammonium) chloride. The lilac deposit is soluble in water, with a lilac-blue colour.

Cobalt chloride is very slowly converted into a bulky red-brown mass, soluble in water with a brown colour. The liquid remains colourless, and takes up no cobalt compound, but some (ammonium) chloride.

Manganese chloride becomes a bulky white mass. The liquid dissolves only a very little manganese compound, but much (ammonium) chloride. The white deposit dissolves in water, yielding a solution only slowly precipitated by ammonia hydrosulphide.

Ferrous chloride (white scales or crystals) becomes a bulky white or nearly white mass. The liquid dissolves only a minute quantity of ferrous compound, and not much chloride. The white deposit dissolves in water, but very rapidly oxidizes and deposits ferric hydrate.

Ferric chloride is converted, with energetic action, into a bulky whitish chocolate-coloured mass. The liquid remains colourless, and takes up only a trace of ferric compound, but plenty of chloride. The deposit is converted into ferric hydrate by water.

Chromic chloride (violet) is only very slowly acted upon, being converted into a dull whitish-pink mass, which imparts to the liquid a cobalt-nitrate-red colour. The deposit is insoluble in water. The liquid may be mixed with water and acidified without experiencing any change of colour; but when heated with hydrochloric acid it changes to a pale chrome-alum colour, and then yields chromic hydrate with ammonia. The liquid may also be made to yield chromic hydrate by nearly neutralizing it with dilute hydrochloric acid and then boiling it.

---

[*] This and all substances tried were used in the anhydrous condition, except where otherwise stated.

Aluminium chloride is gradually converted into a bulky mass, insoluble in water. The liquid takes up a trace of aluminium compound and much chloride.

Phosphorus chloride reacts violently, yielding a white bulky deposit. The liquid takes up much chloride, but only a very little phosphorus compound. The deposit dissolves in water, and gives the reactions of a phosphite.

Phosphoric chloride acts at the surface of the lumps very energetically, a result no doubt of its having absorbed moisture; otherwise it is only very slowly converted into a bulky white deposit, soluble in water. The liquid dissolves out much chloride, but only a little phosphorus compound.

Arsenious chloride is rather energetically converted into a bulky white deposit. The liquid holds much chloride in solution, but no arsenic compound. The deposit is soluble in water.

Antimonious chloride is slowly converted into a heavy white substance, insoluble in water, soluble in warm hydrochloric acid. The liquid takes up much chloride, but no antimony compound.

Antimonic chloride is converted into a bulky precipitate, which only very slowly deposits. The liquid takes up much chloride, but no antimony compound.

Bismuth chloride becomes a bulky mass. The liquid dissolves out no bismuth compound, but much chloride.

Stannic chloride acts with only slight energy, and yields a flocculent precipitate, which, when the chloride has been gradually and well mixed with the liquid, is perfectly soluble in water, the solution becoming clouded when heated. The liquid holds chloride in solution and a little tin compound, and when mixed with water becomes milky, either at once or upon heating.

Platinous chloride is first converted into MAGNUS's green salt, and then rapidly takes up more ammonia and passes into tetrammonio-platinous chloride, much of which dissolves in the liquid. There is sometimes also formed a perfectly white bulky precipitate, insoluble, or nearly so, in water, which is probably a modification of diammonio-platinous chloride.

Platinic chloride (either in the ordinary dry state or after it has been heated till both the water and hydrochloric acid combined with it have been expelled) is scarcely acted upon. Its surface becomes paler, and a trace of it dissolves in the liquid.

Auric chloride (in commercial crystals) is converted into a bulky, orange-coloured, crystalline matter, and at once renders the liquid bright yellow, although not much of it dissolves. The liquid gives a small precipitate of auric hydrate when mixed with water. The orange-coloured deposit is also converted into the hydrate by water.

Sulphur chloride (yellow) reacts very energetically, and gives brown fumes which coat the exposed part of the tube with a brown deposit ($N_2 S$?). When the liquid is kept cool during the admixture of the chloride it assumes a handsome violet colour, which soon passes to a yellow one, and then entirely fades away, with a deposition of sulphur; the liquid then appears to contain one or more of the thionic acids. When the mixture is made, a variegated mass is deposited, consisting apparently of plastic sulphur and a white salt of a thionic acid.

Carbon tetrachloride is insoluble.

Ammonia hydrobromide, potassium bromide, and *potassium iodide* behave like the corresponding chlorides.

Lead iodide dissolves readily. Like that of the chloride, the solution may be mixed with a considerable quantity of water before precipitation takes place. The precipitate that falls is white.

Mercuric iodide (red or yellow form) is turned perfectly white, and then rapidly dissolves to a considerable extent. The addition of water at once causes a curdy white precipitate to fall, which contains almost all the mercury and iodine. This precipitate becomes pale yellow when washed, and then suddenly scarlet-red. The effect of the liquid upon the iodide is quite distinct from that of ammonia and ammonia nitrate dissolved in water.

Fluorspar is insoluble.

Potassium cyanide is nearly insoluble.

Potassium ferrocyanide is very nearly insoluble, but swells up to a bulky mass.

Potassium ferricyanide at once imparts a strong yellow colour to the liquid, and is gradually converted into a pale yellow matter. Both the deposit and the liquid give the reactions of a ferricyanide.

Sodium sulphide reacts with some energy and forms a bulky deposit (sodium nitrate). The liquid becomes charged with ammonia hydrosulphide and fumes strongly in the air.

Zinc sulphide, cadmium sulphide, lead sulphide (native), *mercuric sulphide* (vermilion), and *antimony sulphide* (native) are insoluble and unchanged. (The least trace of zinc oxide in the zinc sulphide is dissolved out by the liquid.)

Ferrous sulphide and *manganous sulphide* (prepared by twice strongly igniting the sulphates with sulphur and cooling them in hydrogen) colour the liquid pale yellow. The manganous sulphide is partly converted into a bulky substance soluble in water. The liquid gives a slight precipitate of sulphur when mixed with water (sulphur itself is insoluble in the liquid); it also yields a slight brownish-black precipitate with lead acetate and acetic acid. On the other hand, it gives, in the case of ferrous sulphide, a slight black precipitate with ammonia hydrosulphide, and, in the case of manganous sulphide, a slight reaction with nitric acid and lead dioxide. (I am not confident that the process employed in preparing these sulphides yields them quite free from oxygen.)

Litharge is soluble. The solution gives a copious white precipitate with water. (Litharge is as efficient as lime or baryta in liberating ammonia from its salts.)

Quick lime hisses as it comes in contact with the liquid, causes an effervescence of ammonia, and dissolves, with the production of a viscid deposit (ammoniated calcium nitrate?).

Magnesia is for the most part converted into a gelatinous matter, but a little of it dissolves. Its action probably resembles that of lime.

Zinc oxide, *cadmium oxide*, and *cupric oxide* dissolve.

Mercuric oxide dissolves. The solution may be largely diluted with water without yielding a precipitate; and hydrochloric acid may be added to it without causing one until the liquid becomes acid, when a white one falls. Nitric and sulphuric acids give no precipitates. Sodium hydrate gives a yellowish precipitate, and potassium iodide a pale yellow one, turned scarlet-red by acids.

Cobalt oxide is slightly soluble, and colours the liquid a faint red-pink. The liquid gives a slight precipitate with ammonia hydrosulphide, which increases on standing.

Ferric oxide. A minute quantity of it dissolves and is thrown down by water as ferric hydrate.

Chromium trioxide reacts rather violently, and is converted into a yellow substance (ammonia chromamate?), quite insoluble in the liquid, but freely soluble in water.

Molybdenum trioxide is converted into a bulky white substance (ammonia molybdamate?), which is insoluble in the liquid, but soluble in water.

Arsenic trioxide is converted into a coherent mass, insoluble in the liquid, soluble in water.

Phosphorus pentoxide reacts rather energetically at the surface of the mass, in consequence no doubt of absorbed water (see *phosphoric chloride*). The rest of the oxide is very slowly acted upon, and undergoes no change in appearance. Much of it dissolves, probably as phosphamate (phosphates are almost or quite insoluble). The changed oxide dissolves quietly in water, and gives the reaction of a phosphate.

Boron oxide is very slightly soluble. The undissolved portions are unchanged in appearance, but the (vitreous) fragments of it become opalescent in water.

Carbon dioxide forms a solid substance, some of which dissolves in the liquid, and which is no doubt ammonia carbamate.

Silica, *alumina*, *tungsten trioxide*, *chromium sesquioxide*, *tin dioxide*, *manganese dioxide*, and *lead dioxide* are unaffected.

Carbon bisulphide is insoluble, but gradually combines with the ammonia.

Potassium hydrate causes an effervescence of ammonia, and rapidly dissolves. Its dissolution is followed by the deposition of most of the potassium as an insoluble compound, which is probably the nitrate.

Sodium hydrate is only slowly acted upon. A little of it dissolves, a crystalline matter (sodium nitrate) is deposited, and the liquid becomes richer in ammonia.

Potassium salts are only very slightly soluble, and in some cases evidently undergo decomposition with the ammonia nitrate.

Sodium salts dissolve to a small extent, or undergo decomposition, so as to yield a sodium compound in solution (sodium nitrate).

Ammonia salts are soluble or insoluble according to their nature. The behaviour of other salts, so far as the basylous radical is concerned, can be judged of by that of the chlorides.

Potassium chlorate is slightly soluble.

Nitrates are soluble salts; *potassium* slightly; *sodium* moderately; *silver* sparingly, the undissolved salt caking together; *lead* freely, the solution behaving like that of the chloride; and *barium* sparingly.

The *nitrites of potassium* and *sodium* are sparingly soluble.

Ammonia orthophosphate is almost insoluble, and is very slowly converted into a bulky substance (ammoniated ammonia phosphate ?).

Sodium orthophosphate is insoluble; so also is the *calcium* salt.

Sodium pyrophosphate is also insoluble.

Sodium metaphosphate is nearly insoluble.

Hydrogen metaphosphate is almost insoluble.

Borax slowly dissolves to some extent.

Ammonia sulphate is quite insoluble. Other sulphates are either quite or nearly insoluble, but are nearly all of them decomposed with the production apparently of insoluble ammonia sulphate. When ammonia nitrate contaminated with sulphate is treated with ammonia gas, the sulphate is left undissolved or non-liquefied.

Potassium sulphate is very slightly decomposed into ammonia sulphate, which precipitates, and potassium nitrate, which dissolves; a bare trace of the sulphate dissolves.

Sodium sulphate is slowly and superficially converted into a bulky crystalline substance, probably ammoniated ammonia sulphate. A trace of the sulphate dissolves and a little sodium (as nitrate).

Silver, *lead*, *magnesium*, *zinc*, *copper*, and *mercury sulphates* are apparently converted into ammoniated ammonia sulphate and more or less completely soluble ammoniated metallic salts.

Barium sulphate is insoluble.

Calcium sulphate is converted into prismatic crystals. Only minute quantities of calcium compound and sulphate dissolve. The crystals are probably an ammoniated calcium salt.

Manganous sulphate is converted into a very bulky substance. Only a trace of manganese dissolves and no sulphate.

Ferrous sulphate (obtained by heating the green sulphate nearly to redness in an atmosphere of hydrogen, and apparently pure) is converted into a very bulky substance of a light chocolate-brown colour. The liquid takes up a very little ferrous compound, but no sulphate. (The colour of the substance deposited is perhaps due to the presence of a little ferric salt: see *ferrous* and *ferric chlorides*.)

Alum is very slowly converted into a bulky substance. The liquid dissolves out a very little aluminic salt, which by water is thrown down as aluminium hydrate and a mere trace of sulphate.

Chromium alum instantly assumes a rich deep green colour, and very slowly imparts a rose-pink colour to the liquid, while a deposit of the same colour gradually forms. The liquid dissolves out potassium salt and a trace of sulphate. The deposit is soluble in water, and gives a violet-pink solution: this solution, or the pink liquid itself when mixed with water, may be boiled alone or with hydrochloric acid, without undergoing any change. Boiled with caustic soda, it loses its colour, and deposits a little chromic hydrate (see the chloride).

Potassium sulphite and *sodium hydrogen sulphite* are very slightly decomposed, and a trace only of sulphite passes into solution.

Ammonia chromate, yellow, crystalline, is converted into a much more voluminous, amorphous, yellow substance, quite insoluble in the liquid, but soluble in water. If not thoroughly dry, the chromate imparts a yellow colour to the liquid, but not otherwise; and even this disappears after a time by the deposition of all the chromium salt.

Ammonia anhydro or *red chromate* is very slowly converted into a yellow deposit, which is not voluminous as in the preceding case. The liquid is not coloured by the salt.

Potassium chromates, yellow and *red*, are slowly acted upon superficially, with the production of a yellow amorphous substance. The yellow chromate faintly colours the liquid, and both yield potassium salt to it. Although in the case of the anhydro chromates and of chromium trioxide (*vide supra*) ammonia chromate is probably formed, it is also evident the ammonia forms ammoniated ammonia chromate. A similar union appears to take place between ammonia sulphate and ammonia.

Lead chromate is converted into a bulky yellow deposit, which by water is reconverted into lead chromate. It hardly colours the liquid, but some lead dissolves.

Potassium permanganate readily dissolves, imparting its splendid colour to the liquid. A very gradual formation of gas soon commences and continues for a day or two, the liquid changing at the same time in colour and becoming deep yellow-brown. The liquid when of this colour is still transparent, but gradually yields a brown deposit and becomes of a fine dilute indigo tint. This shade of colour, lastly, slowly passes into a bright purple colour, which appears to be permanent. In this state the liquid is found not to contain much manganese; its bright colour is spoiled by water and discharged by acids. The brown deposit, on treatment with water, swells up into a bulky flocculent matter, presumably manganic hydrate. Potassium permanganate dissolved in ammonia-water is entirely decomposed in some hours; but in the presence of ammonia nitrate, which by itself is inactive, the permanganate is much more rapidly decomposed by the ammonia-water—probably because of the production, at first, of ammonia permanganate by the nitrate.

Potassium carbonate gradually disappears, some potassium nitrate taking its place. In consequence of the destruction of some of the ammonia nitrate, the liquid becomes surcharged with the ammonia, which has lost its solvent, and effervesces copiously. The liquid contains some potassium salt and some carbonate.

Sodium carbonate behaves like the potassium salt, but to a very limited extent. A similarly marked difference in intensity has been already indicated as marking the action of potassium and sodium hydrates.

Calcium carbonate is not acted upon.

Ammonia carbamate is moderately soluble.

Ammonia oxalate is quite insoluble.

Ammonia acetate (moist crystals dissolve freely).

Benzene, oil of turpentine, indigo, strychnine, wax, and *olive-oil* are insoluble.

Cane-sugar, gum-arabic, litmus, tannin, phenol, and *aniline* are soluble.

Gelatin is converted into a flocculent substance.

Butyric ether is slightly soluble without decomposition.

Methyl iodide is insoluble, but is slowly decomposed. Gas escapes, which is probably methylamine.

Ether is insoluble, but it causes the decomposition of the liquid, the ammonia bubbling through the ether, and the nitrate depositing.

Chloroform dissolves to a small extent, and separates again unaltered on the addition of water.

10. The liquid compound of ammonia nitrate and ammonia is a good electrolyte. With two Bunsen's elements hydrogen gas is freely evolved at the negative electrode, and one third of its volume of nitrogen gas at the positive electrode, as in the electrolysis of aqueous solution of ammonia. Large quantities of ammonia gas escape along with these gases by diffusion, so that the electrolysis appears to take place much more rapidly than it does do in reality. The loss of ammonia causes deposition of ammonia nitrate to occur, but a great difference is observed between the quantities of it deposited at the two electrodes. At the positive electrode, where the escape of gas is *less*, the nitrate soon begins to precipitate and also to crust the surface of the liquid; while at the negative electrode, where the escape of gas is *greater*, the nitrate does not appear for some time, and then only slowly,—that is to say, ammonia nitrate accumulates at the positive electrode, and ammonia itself at the negative one. The electrolysis of the nitrate and the secondary decomposition of the ammonia accounts for the above phenomena: for $H_4N \cdot NO_3$ being resolved into NH_4 and NO_3, ammonia and hydrogen are set free at the negative electrode, while NO_3 appears potentially, though not actually, at the positive electrode, where it enters into reaction with ammonia to form ammonia nitrate and nitrogen, thus:—

$$3NO_3+4NH_3=3NO_3\,NH_4+N,$$

the N being equivalent to the H_3, which appears simultaneously at the negative electrode.

No reduction of the nitrate to a less oxidized salt takes place at the negative electrode. This is a fact of some interest, because it is opposed to the hypothesis that a *nascent* body possesses a chemical activity not belonging to it in its ordinary free condition; for here is basylous hydrogen, at the moment of its liberation, exerting no action on the nitrate, although zinc and other metals so readily reduce it under various conditions, including that of its solution in ammonia*.

---

* Ammonium amalgam also appears to have during its decomposition no reducing action upon a nitrate, a fact, however, which may be due to the amalgam not being really a compound of ammonium.

When the positive electrode is formed of *platinum* or *iron*, it is unacted upon during the electrolysis; but when it is formed of *silver*, *mercury*, *lead*, *copper*, *zinc*, or *magnesium*, it is corroded, and no nitrogen is evolved. The silver, lead, and copper electrodes readily dissolve as nitrates, the copper one soon becoming coated with an azure-blue deposit. Mercury dissolves only slightly, but its surface becomes covered with a grey deposit. Zinc and magnesium dissolve as nitrates, but somewhat more slowly than the other metals mentioned, a fact probably to be accounted for by their tendency to direct or local action upon the nitrate.

X. *On the Organization of the Fossil Plants of the Coal-measures.* — Part IV. Dictyoxylon, Lyginodendron, *and* Heterangium. *By* W. C. Williamson, *F.R.S.*, *Professor of Natural History in Owens College, Manchester.*

Received December 4, 1872,—Read December 19, 1872.

On February 20th, 1866, Mr. Binney gave to the Literary and Philosophical Society of Manchester a brief description of a new plant from the Lower Carboniferous beds of the neighbourhood of Oldham. The following extracts from the 'Proceedings' of the Society embody some of the chief points of that description.

"It evidently belonged to the genus *Pinites* of Witham, since changed by Endlicher and Brongniart into *Dadoxylon*." It "has a medullary axis composed of irregular polygonal cells separated by intervening spaces vertically, and thus forming a kind of discoid pith." "This is separated from lunette-shaped bundles of hexagonal tubes arranged in a convex form from the pith inwards, and lessening in size as they pass outwards into wedge-shaped masses of four-sided subhexagonal cellules arranged in radiating series, and divided by large medullary rays or bundles, which appear to originate in the lunette-shaped masses. On the outside of this internal radiating cylinder are other lunette-shaped bundles similar to those in the inside." "Then comes a narrow zone of lax tissue, which has been a good deal disarranged. Outside this are some thin wedge-shaped bundles of cellules full of dark carbonaceous matter, and arranged in radiating series of varying sizes, separated by lax tissue, probably representing the bark of the tree."

"In the longitudinal section the cellules are seen to be greatly elongated and divided with oblique and transverse dissepiments placed at great distances. Two of the walls, viz. those facing the medullary rays, are regularly reticulated with six, seven, and eight series of hexagonal areolæ arranged regularly but not in a line."

"In the tangential section the walls of the cellules also show a reticulated appearance, something like that previously noticed, but not in so marked and distinct a manner; and the medullary rays or bundles, in their section, show numerous irregular series of small cellules of one to four, and more rarely much larger cellules."

"The areolæ on the walls of the cellules are more numerous than in any species of *Pinites* or *Dadoxylon* that have hitherto come under my notice, the *Pinites medullaris* of Witham having the walls of its elongated cellules with two, three, and four series of contiguous areolæ, and those only on the walls parallel to the medullary rays, whilst in my specimen they are reticulated with six, seven, or eight, and not only on such walls, but also on the walls at right angles to the medullary rays."

To the plant thus described Mr. BINNEY gave the name of *Dadoxylon Oldhamium*.

The above object came under my notice at an early period of my investigations amongst the plants of the Coal-measures, and I soon became convinced that it was *not* a *Dadoxylon*. In a brief memoir published in the 'Monthly Microscopic Journal' for August 1869, I pointed out that, since the appearance of ENDLICHER'S memoir on *Dadoxylon*, "numerous specimens of woody stems have been found, *transverse* sections of which exhibit a structure identical with that of living conifers; but longitudinal sections show that the vessels or fibres are altogether different from the coniferous or discigerous type. Instead of bearing rows of disks, and those only on the surfaces of the vessels parallel with the medullary rays, their entire walls are covered with reticulations formed by the deposition of lignine *in the interior* of the vessels." Then, after describing some figures, I proceeded to say, "These two figures represent reticulated fibres as seen in several distinct plants found in the Coal-measures. Whether these prove to be different species of one genus, or whether they will require more than one genus for their reception, remains to be seen. But certainly none of them can be regarded as Dadoxylons, since they belong to an altogether different type of structure."

"It appears necessary, therefore, to establish a new genus for all the plants whose woody cylinders consist of reticulated fibres, and the name of *Dictyoxylon* appears an appropriate one for it. I should propose for the present to include in this genus *all* the reticulated types, whether their medullary rays consist of one or of several vertical series of cells. At some future time their further separation into two or more genera may be requisite."

The memoir from which the above quotations are taken contains two errors—one of observation, and one due to a misprint. In some examples, in which the structure was imperfectly preserved, I found it difficult to distinguish the lenticular disks of the supposed conifer *Dadoxylon* from the reticulated areolæ of the Dictyoxylons. The two specimens numbered 7 and 11 in the Plate illustrating the memoir had their vessels in this imperfect condition, and I fell into the error of regarding them as Dictyoxylons. I have since ascertained, beyond doubt, that they are both Dadoxylons*. The second error is a misprint of *Dictyoxylon* for *Dadoxylon* in the eleventh line from the end of the memoir. As it stands, the supposed coniferous fruit known as *Trigonocarpon* is indicated as possibly belonging to the former genus, whereas I intended to suggest the possibility of its relation to the latter one.

At the Edinburgh Meeting of the British Association in 1871, I described yet more definitely the characteristics of my genus *Dictyoxylon*, especially as represented by three plants, viz. Mr. BINNEY'S *Dadoxylon Oldhamium*, a new species from Burntisland to which I gave the name of *Dictyoxylon Grievii*, and a third form from the Lancashire Coal-measures, to which I assigned the name of *D. radicans*. Further investigation into the history of the latter plant has led me to separate it from *Dictyoxylon*, under the provisional generic name of *Amyelon*[*]. My genus *Dictyoxylon*, therefore, is limited, for the present, to the two other species already mentioned, at least so far as this country is concerned. M. RENAULT recently brought before the Academy of Sciences at Paris a notice of some French examples of the genus from the Coal-measures of Autun; but as his memoir has not yet been published, I do not know what forms have been discovered by this excellent observer[†]. I may further observe I have recently found that other genera, *e. g. Asterophyllites*, sometimes possess reticulated vessels like those of *Dictyoxylon* and *Amyelon*.

---

* The correction of this error is important, since fig. 11, especially, represents a plant with a Sternbergian pith, whereas no such pith occurs in any known true *Dictyoxylon*.

Dictyoxylon Oldhamium proves to be one of the most common of the plants found in the calcareous nodules discovered in the lower Coal-measures near Oldham and other parts of Lancashire and Yorkshire having the same geological horizon. The vast majority of the specimens are young stems or branches, rarely exceeding an inch in their greatest diameter: nevertheless, as I shall show in the course of this memoir, the plant attained to an arborescent form. It was not an articulated plant, neither was it, in the usual sense of the word, a dichotomous one. It had terminal branches of small size compared with the dimensions of the main axis, but no traces of actual leaves have been discovered in connexion with any specimen that I have seen. The axis possesses the three distinctly marked divisions of pith, wood, and bark, each of which organs requires a detailed description.

The Pith.—As in the Lepidodendroid plants described in my last memoir[‡], this structure was of very small size in young twigs, and gradually enlarged with the increasing dimensions of the stem, at least up to a certain stage of growth. Its average size, relatively to that of the entire stem, is seen in Plate XXII. fig. 1, which represents a transverse section made by Mr. BUTTERWORTH. Fig. 2 represents the medullary axis and innermost portion of the ligneous zone of a still younger stem; whilst fig. 4 represents a similar section of an entire ligneous cylinder, with its contained medullary axis and a little of the innermost bark. Fig. 3 is a segment of the ligneous zone and the adjacent part of the medullary axis of another transverse section; and fig. 5 exhibits a group of the cells of the true medulla, also intersected transversely.

The pith (*a*) is an undivided parenchymatous tissue of a very regular kind. The intervening spaces, described by Mr. BINNEY as separating the cells vertically, and converting the pith into a discoid one, have no existence in well-preserved specimens, but have been the result of desiccation or some other accidental cause. The individual cells vary in size, but they usually range between ·0025 and ·0033[§]: in the vertical section, and in perfect specimens, they often exhibit a very decided disposition to arrange themselves in perpendicular rows, as is so often the case amongst the Lepidodendroid plants; with this trifling exception the tissue is an ordinary form of parenchyma. I shall in the course of the memoir give my reasons for concluding that the history of this tissue in *Diploxylon Oldhamium* is similar to that of the Lepidodendroid plant described in Part III., viz. that it had scarcely any existence in the very young twigs, the central axis of each of which has been chiefly occupied by a mass of vascular tissue; but as the plant grew, the primitive cells which lurked amongst the vessels multiplied themselves, forming a true medulla, which pushed the vascular tissues outwards, where they permanently occupy a position analogous to, if not even physiologically identical with, that of the vascular medullary cylinder common to plants of the Lepidodendroid type. Thus in fig. 2 we have these medullary vessels at *c*, constituting an almost unbroken ring enclosing the true medulla. The large and but partially detached masses of vessels occupy the greater portion of the medullary area; but as we proceed to examine a series of larger and older examples, we discover that these vascular masses become widely separated from each other (Plate XXII. fig. 1, *c*, and opposite to *c c* in fig. 4). They now form irregularly triangular bundles of vessels, projecting into the medulla from ·0165 to ·02 in ordinary specimens, and adhering by their peripheral margins to the innermost surface of the ligneous zone, as represented in fig. 3, *c*, and in Plate XXIII. figs. 6, *c*, & 7, *c*. These masses do not appear to increase in size with the growth of the stem, since in a larger example of the latter, in which the ligneous zone alone has had a diameter of at least an inch, these vascular bundles do not project into the medulla more than from ·0166 to ·025. The component vessels of each bundle vary much in size. As in the Lepidodendroid medullary cylinders, they are arranged irregularly, and not in radiating series. They have all reticulated walls. In fig. 4 there are some conditions which I have not found in any other example, and which may have been the accidental results of partial desiccation or some similar disturbing cause: the continuity of the cellular medullary tissue is interrupted at the centre, and the cells exhibit a tendency to dispose themselves in irregular lines, radiating towards the periphery of the medulla.

---

[*] See 'Proceedings of the Royal Society,' vol. xx. p. 436 (1872). This plant proves to be the root of *Asterophyllites* (Proceedings, vol. xxi. p. 397, 1873).

[†] M. RENAULT has kindly supplied me with sections of the plant to which M. BRONGNIART had applied my generic name. It proves to be a Sigillarian plant.—Sept. 7, 1873.

[‡] Philosophical Transactions, 1872, part ii. p. 283.

[§] As in the previous memoirs, all these measurements are given in decimal parts of an inch.

The Ligneous Zone.—This is a cylinder of vessels arranged in radiating planes, which latter are really vertical laminæ separated by large and very remarkable medullary rays. In its normal state the cylinder has been an unbroken one, as represented in Plate XXII. fig. 4, *d*; but, owing to various causes, this continuity is frequently disturbed in the fossils, as seen in fig. 1. Each lamina commences, at its inner margin, either at the medullary cells or at one of the triangular medullary vascular bundles. The innermost vessels are usually the smallest ones, a gradual increase taking place in their diameter as we follow them towards the periphery. This enlargement, however, soon reaches definite limits. Their diameter in the smaller stems rarely exceeds ·0033, and in the largest ones I have found none more than ·005. In the young plants many of these laminæ consist of a single linear series of vessels, as shown in the several figures 2, 3, 6, and 7; and in such examples we have rarely more than four or five linear series in any undivided wedge.

In larger and older specimens I have counted as many as thirteen such laminæ in an apparently undivided series, though a tangential section of such wedges would probably show some thin medullary rays separating the laminæ, but which were not observable in the transverse section. The following Table gives the mean results of a series of measurements of the thicknesses of these compound wedges in a very large stem, beginning with those in which each wedge consists of a single linear series of vessels, and ascending to those in which I have found as many as thirteen.

Number of laminæ in each wedge.	Entire thickness of wedge.	Mean thickness of the component laminæ.
One row of vessels . . .	·0023	·0023
Two rows „ . . .	·0041	·0020
Three „ „ . . .	·0058	·0029
Four „ „ . . .	·007	·0017
Five „ „ . . .	·007	·0014
Seven „ „ . . .	·0094	·0013
Eleven „ „ . . .	·015	·0013
Thirteen rows of vessels . .	·015	·0011

The second column of figures shows that as the wedges increased in size there was a gradual diminution in the thickness of their component laminæ—the result partly of their mutual pressure impeding the expansion of the vessels to their normal dimensions, and partly of the fact that these larger wedges contain more than the average of young laminæ which have been intercalated, and which may not have reached their full development. In young stems we find that the dimensions of the wedges are somewhat larger than those recorded in the above Table.

On tracing these wedges in such sections as Plate XXII. fig. 3, from their medullary to their peripheral margins, we find that many of them consist of a single lamina of vessels throughout their entire course; but such limited examples rarely, if ever, occur in the larger stems. As shown in fig. 3, *e*, after proceeding outwards for a little distance, the single row of vessels divides into two smaller ones, which in turn become yet further multiplied in the thicker stems.

These vascular laminæ are divided from one another by large medullary rays (*f*), which are very conspicuous, even in the transverse sections, in which they are usually composed of several rows of cells with thin walls running in a radial direction, their square-ended cells being elongated in the same direction. In tangential sections (Plate XXIII. fig. 8) we see that the ligneous zone exhibits the appearance of a network, of which the woody laminæ (*e*) represent the threads, and the medullary rays (*f*) vertically elongated lenticular meshes. Two things strike us on regarding such a section, viz. the immense number of these rays and their large size. In large stems they frequently have a vertical length of a quarter of an inch, and sometimes even more, whilst in such specimens ·125 is a common size; their diameter ranges from a thin column of single cells up to dense cellular masses (fig. 8, *f'*), with a diameter of from ·0016 up to ·01, the cells of which exhibit the aspect of ordinary parenchyma. On turning to radial sections (Plate XXIII. fig. 9), we see that these rays (*f*) present as perfect an example of mural arrangement as could be found in any Dicotyledonous plant. In whatsoever direction we make sections of the woody zone of this plant, we equally obtain clear proof that the cellular tissues of the medullary rays constitute fully half of its substance. Occasionally, as at Plate XXIII. fig. 8, *f''*, we find individual rays consisting of but three or four cells, but such restricted examples are rare.

The Bark.—This consists of three very conspicuously distinct layers—an inner parenchyma, a prosenchymatous layer, and an outer parenchyma; but practically four such may be distinguished, since the surface of the innermost one of the three, which is in immediate contact with the wood, becomes differentiated into a cambium-layer.

Inner Parenchyma.—This innermost division is not always to be found in a distinctly marked form. When present, it consists of a uniform series of exceedingly delicate cells (Plate XXII. fig. 1, *g*, & Plate XXIII. fig. 6, *g*), which have a somewhat constant diameter of from ·001 to ·002. In the transverse section they present the ordinary parenchymatous form; in the longitudinal one they exhibit a tendency to arrange themselves in vertical lines. At its outer boundary this stratum merges in an almost equally delicate parenchyma, but composed of somewhat larger cells (Plate XXII. fig. 1, *h*, Plate XXIII. fig. 7, *h*, & Plate XXIV. figs. 10, *h*, & 11, *h*). Both the inner and outer portions of this double parenchymatous layer are characterized by the presence of large, irregularly star-shaped patches (Plate XXIV. fig. 11, *h'*) of cells of a dark colour. These might at first be supposed to be accidental discolorations due to local mineralization; but I am satisfied that such is not the case. These cells are rather larger and have denser walls than those amongst which they are imbedded; and they form so constant an element in this portion of the plant, that I can have little doubt as to their having constituted a feature of the living structure, resembling possibly the dark-coloured cells so common in the rootlets of Ferns and of some *Lycopodiaceæ*. Those in the inner parenchyma are much larger than those of the outer parenchyma, the latter often consisting of but one or two well-marked dark-coloured cells. In studying the Dictyoxylons, these pigment-patches supply an excellent guide, enabling us to distinguish between the parenchyma of the inner bark and that of the medullary rays*. In the fossil specimens this cortical parenchyma frequently appears as if trailed about in a remarkably irregular manner; but this is probably a result of partial desiccation prior to fossilization.

---

[*] Whilst describing this part of the bark, a specimen now under my microscope reminds me once more of the necessity of guarding against the misleading influence of Stigmarian rootlets, the great enemies of the young palæophytologist who studies the organization of these coal-plants. In the specimen referred to, a long narrow strip of clearly defined cellular tissue of peculiar aspect runs longitudinally through the portion of the bark just described, imbedded amongst the true cortical tissues in a way that would inevitably mislead an observer whose eye was not thoroughly familiar with the aspect of these rootlets. In a previous memoir I have called attention to the universal diffusion and marvellous penetrating power of these intruders; but I think the latter attribute has reached its acme in one specimen which I have recently met with, in which a large rootlet has been penetrated longitudinally by a smaller one; and the latter, in its turn, contains a third within its

In the innermost layer just described we find large longitudinally disposed vascular bundles, the presence of which, under various conditions, constitutes one of the characteristics of the genus *Dictyoxylon*. These bundles sometimes, though rarely, occur singly; but even when they do so we can generally trace a radial line, indicating a division of the bundle into two lateral halves. An example of this latter condition is seen in Plate XXIII. fig. 7, *z*. More ordinarily we find two such bundles (Plate XXV. fig. 17, *z*), evidently resulting from the vertical division of a cluster, like that just referred to, into two nearly equal parts. The transverse section of each bundle is now somewhat of a rounded triangle in form, the semiovoid form being due to the same vertical division of an oval double bundle.

Such undivided bundles as that of Plate XXIII. fig. 7 have a longer diameter of ·033. When the two halves become separated, as in Plate XXV. fig. 17, by a decided and sometimes considerable interval, each half attains to about the same dimensions as the undivided whole, making it clear that as the division progresses the component vessels increase in size. The diameters of these vessels vary from ·003 to ·0015. On examining the bundles in a longitudinal section (Plate XXIV. fig. 11, *z*), we observe that they preserve their parallelism with the exterior of the ligneous zone, and do *not* seem to take their rise in, or diverge from, the latter structure, as is the case with the foliar bundles of the Lepidodendroid plants, with which, at the first glance, we should be tempted to compare them. Their component vessels are chiefly reticulated ones, like those of the woody zone; but along with these are other and usually smaller ones, which are distinctly of the barred type. Such barred vessels are, as I have already shown, entirely absent from the true ligneous zone.

In the great majority of cases I have counted four of these double bundles in each transverse section of the entire stem. In Plate XXII. fig. 1, I only discover three pairs, whilst in Plate XXII. fig. 4, I have reason to believe that there were as many as five. The positions of these double bundles bear a remarkable relation to those of the separate masses of the original medullary cylinder (Plate XXII. figs. 2, 3, & 4, & Plate XXIII. figs. 6 & 7, *c*), which remain attached to the medullary surface of the ligneous zone. Where the relative positions of the organs have not been disturbed by mechanical pressure, as is often the case, these cortical bundles are disposed externally to the woody zone at points intermediate between those of the medullary clusters of vessels. I have seen no exception to this rule. Of course, this alternation is less obvious in young stems, in which, like Plate XXII. fig. 2, the medullary cylinder is not yet broken up into distinctly separated portions, than in older ones, though even here, as seen in Plate XXIII. fig. 7, the evidence of this relationship is not wanting; but where, as in Plate XXII. figs. 1 & 4,

---

cylinder. Whilst referring to the necessity for incessant vigilance against this source of error, I may express my absolute conviction that the vascular bundles which Mr. BINNEY has figured as belonging to the medullary tissues of *Halonia* ("Observations on the Structure of Fossil Plants, &c." (Palæontographical Society, 1871), plate xvi. figs. 2 & 5, and plate xvii. fig. 5) are merely examples of these intrusive rootlets.

the growth of the stem has distinctly separated the medullary vascular buttresses widely apart, we distinctly see the intermediate arrangement of the peripheral bundles. Examination of a large series of these transverse sections further shows that the undulating outline of the ligneous zone, best seen in Plate XXII. fig. 4, and which is always more or less present in uncompressed stems, is due to the relationships just pointed out. That outline is centrifugal opposite to where the medullary bundles are located (*c*), and bulges inwards or becomes centripetal where the cortical bundles are placed (*z*). The latter might have been introduced to compensate for the absence of the former for the purpose of equalizing the resisting power of the walls of the entire, combined, vascular cylinder. I shall shortly point out the existence of a peculiar series of exogenous additions made to many of these cortical bundles.

Prosenchymatous Layer.—Transverse sections of the stem at once arrest the attention of even casual observers by the remarkable aspect of this layer, which is well represented in Plate XXII. fig. 1, *k*. It bears a strong resemblance to a clock-face, upon which the figures have been inscribed in Roman numerals. On magnifying more highly the dark bands which give this aspect to the section, as is done to three of them in Plate XXIV. fig. 10, *k'*, we discover that they are due to irregularly defined radiating laminæ of prosenchyma, the walls of the component cells of which are thickened by internal deposits, converting them into true fibres. These fibrous bands alternate with lenticular masses of ordinary cellular tissue, which displays different forms of cells, not only in different plants, but in different parts of the same plant. On making tangential sections of this portion of the bark (Plate XXIV. figs. 13 & 15, & Plate XXV. fig. 14, *k'*), we learn that these fibrous laminæ not only undulate as they ascend vertically through the stem, but bundles of fibres regularly detach themselves obliquely from one lamina to unite themselves with those of a contiguous one, thus mapping out the section, by dark continuous lines, into a series of lenticular spaces (*k''*). At the first glance these lenticular or rhomboidal areolæ might be mistaken for those characterizing the bark of a *Lepidodendron*; but closer examination shows that there is no real identity between the two structures. The fibrous laminæ bear a much closer resemblance to the structure of the liber in Dicotyledonous plants, especially as seen in the lace-bark tree (*Lagetta lintearia*) and other Thymelaceæ. In tangential sections of young stems, the areolæ described by these fibrous layers are longer in proportion to their breadth (Plate XXV. fig. 14, *k''*, & Plate XXIV. fig. 15, *k''*) and also less regular in their arrangement than is the case with older ones. Plate XXIV. fig. 13 represents part of the bark of a stem, the ligneous cylinder of which, apart from its bark-bundles, has been rather more than two inches in circumference. We here see that the areolæ (*k''*) have not only become less lenticular and more rhomboid in their form, but have also arranged themselves with greater regularity in pseudo-spiral lines than is the case with many other stems. In these respects, however, individual specimens vary very greatly.

The thickness of this prosenchymatous layer of the bark, as a whole, is usually, in young stems, from ·1 to ·145: in some very young ones it did not exceed ·033. The fibres of the radiating laminæ have a diameter varying from ·0023 to ·0006, their more usual dimensions being from ·0012 to ·0008. It is very difficult to measure their length, because, owing to its amount, which is considerable, and to their interlacing freely within their respective bundles, it is almost impossible to see the two extremities of each fibre; it is, however, sufficiently great to give them an almost vascular character. Practically they are bast-fibres. When we do see their extremities, as in Plate XXIV. fig. 15, *k'*, we observe distinctly the fusiform terminations of the cells; but where they come in contact with the parenchyma enclosed within the areolæ, we sometimes notice a very rapid transition from the one type to the other, through some elongated square-ended modifications of cellular tissue.

I have referred to the cellular tissue filling up the lenticular or rhomboidal areolæ as parenchymatous, but it varies immensely in the same plant. Thus in the transverse section (Plate XXII. fig. 1) we find these spaces occupied throughout the greater part of the section by ordinary parenchyma, as seen in Plate XXIV. fig. 10, *k''*; but on the extreme right of fig. 1 they are filled with transversely elongated prismatic cells, which often almost extend from one fibrous lamina to another, their long axes being parallel with the circumference of the bark. We see similar differences in the tangential sections: thus, in Plate XXIV. fig. 15, *k''*, these cells are parenchymatous, whereas in the greater part of fig. 13, *k''*, & Plate XXV. fig. 14, *k''*, they are prismatic, or even mural, their long axes being transverse to that of the stem. In the radial vertical section (Plate XXIV. fig. 11, *k'*) we see the prosenchymatous layer forming an irregular wavy line. The cells occupying the areolæ vary much in their dimensions; but when they assume the parenchymatous form they have a somewhat larger diameter than characterizes the contiguous fibres, or from ·0033 to ·0015. The internal cavities of the fibres are usually more or less filled with carbonaceous matter (Plate XXIV. fig. 10, *k'*), their ligneous walls having evidently possessed some peculiar osmotic properties not possessed by the ordinary cellulose of the parenchyma.

In the large majority of my specimens I detect no tissue external to the remarkable one just described; but in some young stems, more perfect than the rest, the parenchyma of the rhomboidal areolæ spreads out into a thin parenchymatous subepidermal layer (Plate XXII. fig. 1, *l*, & Plate XXIV. fig. 10, *l*), at the outer surface of which we often see small irregular projections. Nothing approaching a true epiderm has yet been found*. The thin layer just named seems to have disappeared during growth, as if it were an epiderm and was not renewed.

In no instance has a trace of a foliar vascular bundle, like those of the *Lepidodendra*, been found in the cellular areolæ of the bark. This fact alone demonstrates one difference between these rhomboidal areolæ and the leaf-scars of *Lepidodendron* and *Sigillaria*;

---

* At the Meeting of the British Association in 1871, Mr. Binney stated that he had found a yet more peripheral layer. I have examined some hundreds of these stems, but have seen no trace of any thing like what he there described.

and it further stands related to the equally remarkable fact that no trace of a true leaf has yet been met with connected with these stems: and in but one solitary instance have I seen any of the cortical vascular bundles within the area of the prosenchymatous zone; they are limited to the inner bark. To these points, however, I shall shortly return.

Having thus examined the ordinary structure of the *Dictyoxylon Oldhamium*, we may now turn to some special points connected with its growth. I have already pointed out that whilst in some specimens the ligneous zone is thin, consisting of but a very limited number of vessels, as in Plate XXII. fig. 4 (which condition is still more obvious in the case of the older woody layer, *e*, of Plate XXIII. fig. 6), I have obtained from Mr. Nield one magnificent axis in which the woody cylinder and its contained medulla has been at least eighteen inches in circumference. The thickness of the wall of this vascular cylinder has been at least 2½ inches; and since the specimen is weathered and water-worn*, it may have been of even larger dimensions. In this specimen, assigning to each vessel a mean diameter of ·004 would give us between six and seven hundred vessels in the linear series of each radiating lamina of the wood. Dimensions like these at once suggest the existence of some exogenous mode of growth. But fortunately we are not left to mere inference on this point. As in the case of the Diploxyloid stems described in my last memoir, I have obtained several specimens which unmistakably demonstrate the operation of this exogenous development of the Dictyoxylons. Of these, Plate XXII. fig. 4 represents one in which there are three distinct rings of vessels; and Plate XXIII. fig. 6 is a still more enlarged figure of a second example, drawn with great care, in which there are but two concentric growths. In the former example the boundary line between the innermost and middle ring is but faint, because the vessels of the latter have already expanded to their normal dimensions. The outermost ring (Plate XXII. fig. 4, *e'*) is less completely developed; hence the vessels have not attained to much more than half their size. In Plate XXIII. fig. 6 the distinction between the vessels belonging to the inner and older ring (*e*) of the ligneous zone and those of the newer one (*e'*) is very marked: the latter are of very small size; not larger, indeed, in many examples, than the inner bark-cells (*g'*) in which they have developed themselves. The specimen from which this figure was taken puts beyond the possibility of doubt the existence of exogenous growth amongst these plants.

But there remains another curious evidence of the pseudocambial action of the innermost bark. I have already depicted the usual forms of the cortical vascular bundles in Plate XXIII. fig. 7, *z*, & Plate XXV. fig. 17, *z*. A similar bundle, copied from the specimen shown in Plate XXII. fig. 1, is seen in Plate XXVI. fig. 18. In this example the bundle is less sharply defined than in those already described; and some of the vessels in its central portion have the appearance of being intervascular cellular tissue. I presume that at least some of this appearance is but the result of imperfect mineralization. In Plate XXV. figs. 19, *z*, & 20, *z*, we have the two bundles belonging to another of the clusters of Plate XXII. fig. 1, and which are enclosed within the innermost bark-layer: their relative positions in the bark were similar to those which they occupy upon the Plate. On the outer or cortical side of each we find several diverging lines or laminæ of vessels (z'), of which those nearest the space separating the two bundles are the longer ones, whilst the others become successively shorter as we diverge from that space. We have here unmistakable growths superadded to the exterior margins of the two bundles, similar, in all essential respect, to those added by the pseudocambium to the exterior of the ligneous zone, and apparently through the action of the same pseudocambial cells. Though I do not by any means find these conditions of the cortical bundles repeated in all the specimens of *Dictyoxylon*, they are frequently met with. Plate XXV. fig. 21 exhibits a yet more remarkable modification of these bundles that I have occasionally observed. In this instance the original bundle of non-radiating vessels has become firmly incorporated with the periphery of the ligneous zone (*e*), and the exogenous additions have been made to its exterior in such a manner as to form a wedge-shaped buttress (z'), running vertically down the ligneous cylinder. I have dissected several of these buttresses, and find that when radial sections of the ligneous zone pass directly through them they exhibit all the ordinary appearances of, and are scarcely distinguishable from, that zone; indeed, as seen in such sections, they only appear to be outward prolongations of it. In some of the examples, as is the case with the one figured, the central non-radiating bundle of vessels has its details less clear than in others. Where these *are* distinct, I think they show that the bundle is in the same state as that represented in Plate XXIII. fig 7, *z*, viz. in its undivided condition. This explains why, in these wedge-shaped growths, we never find the twin bundle. The exogenous growth, which now binds the vessels together, has commenced before the separation of the cluster into two parts was effected. These details are trivial, but they help to throw light upon the nature of the objects in question.

---

* It was found in a watercourse intersecting the Lower Coal-measures at a locality near Oldham, known as Har Culver (Higher Culvert).

Another remarkable feature of these organisms yet remains to be examined. So far as outward appearances are concerned, *Dictyoxylon* might be declared to have been a simple, unbranched stem. In no one instance have I found an example which exhibits any obvious division or bifurcation of the stem, such as is common amongst the *Lepidodendra*. Nevertheless several examples have come into my hands in which branches of some kind have existed. The first trace which I met with of this character was in a tangential section of the bark made by Mr. BUTTERWORTH, and represented in Plate XXV. fig. 14. One of the cellular areolæ of the prosenchymatous layer of the bark has evidently been modified and enlarged to allow the branch (*y*) to escape through it. The cellular parenchyma of the middle bark has been condensed into an oval ring, through which the bundle has emerged. This ring is seen further enlarged in Plate XXVI. fig. 22, *h*; within it is a space (*g*) which was, I have no doubt, originally occupied by the delicate parenchyma of the innermost bark, prolonged as an investing layer from the central cylinder of that tissue, but the cells of which have now disappeared. The centre is occupied by a round and well-defined mass of vessels of two kinds, which the section, though made tangentially to the parent bark, has divided transversely, showing that the bundle passed out of the original stem at right angles to its vertical axis. The greater portion of the section consists of a cluster of vessels (*c*) not arranged in radiating series, larger ones occupying the centre and smaller ones the periphery of the cluster. In the former portion some of the vessels have almost disappeared; but I have no doubt that originally there was an almost solid mass of them interspersed with some delicate cellular tissue. The periphery exhibits a narrow ring (*d*) of small vessels which are arranged in radiating series, the radiating lines being separated by medullary rays. Here we have obviously the first growth of an exogenous ligneous zone.

Plate XXV. fig. 16 represents a second and yet more beautiful example, from one of the larger specimens to which reference has already been made. The cellular tissue (*h*), in which the branch-section is imbedded, is the central parenchyma of the bark of the parent stem, intersected tangentially: we have here, as before, the condensed ring of this latter tissue (*h'*) enclosing the vacant space which I presume to have been occupied by a prolongation of the innermost bark-layer. The section of the branch, which is as perfect as possible, exhibits the same general arrangement of the tissues as that which appears in the previous example. The medullary axis is occupied, as in Lepidodendroid twigs, by a cylindrical bundle of vessels; this, again, is surrounded by a well-developed ligneous zone, consisting of about twenty-three clearly defined, radiating vascular wedges, separated by equally distinct medullary rays. The exogenous development of this branch has advanced further before it emerged from the bark than in that just described. Tracing these branches inwards in order to ascertain their origin, we must return to Plate XXII. fig. 1, *x*, in the interior of which we discover a section similar in all respects to the last one, save that it has attained to a yet more remarkable degree of development before escaping from the pseudocambial and inner parenchymatous bark-layers. Plate XXVI. fig. 23 is a carefully drawn enlargement of a portion of this branch-section. Here, again, we have at *c* the compact mass of vessels forming the medullary axis, radiating from which we have a series of vascular wedges (*d*), which, in the perfect section, are nearly forty in number; these, again, are separated by clearly defined medullary rays (*f*) of relatively large size, especially on the left and lower sides of the figure. As the section has traversed this part of the branch somewhat obliquely, we readily trace the mural arrangement of the cells constituting these rays; whilst at their outer extremities we also see, with similar distinctness, how the cells merge in the equally delicate ones (*g*) of the pseudocambium of the parent axis (Plate XXII. fig. 1, *g*). Approaching nearer to the central axis of the stem, we find in Plate XXIV. fig. 11, *x*, another of these branches penetrating the ligneous zone (*e*). As already stated, this figure represents part of a tangential section of a ligneous cylinder made midway between the medulla and the bark; but whilst the *wood* is intersected *tangentially* on the left-hand of the figure, the *bark* on the right is cut through almost *radially*—results due to the cylindrical form of the branch. The woody zone displays the usual innumerable medullary rays separating the woody wedges; but at the lower part of the figure the latter tissues are yet further deflected right and left, to allow a large vascular bundle to pass out between them. This bundle and the surrounding tissues are shown, still further enlarged, in Plate XXIV. fig. 12. The section has divided the vessels in the centre of the bundle transversely; but the more peripheral ones trail across the field of view in irregularly radiating lines, which, at their peripheral ends, appear to merge with the curving vessels of the parent axis. Having obtained another specimen similar to that just described, I made a series of tangential sections of it, and found that the divergent bundle of vessels diminished rapidly in size as I approached the medullary axis, and became almost, if not wholly, wanting before reaching the inner surface of the ligneous zone, affording an additional illustration of the exogenous development of both stem and branch. The section Plate XXVI. fig. 24 throws additional light upon these arrangements: this is part of a transverse section of a stem, but the section has passed somewhat obliquely through one of these branches; besides which, owing to the curvilinear direction followed by the branch, the section has divided its upper half almost transversely, whilst its lower or inner portion is intersected more longitudinally. The peripheral portion of the section shows clearly that this branch consisted of laminæ arranged in radiating order; whilst the more central part demonstrates that these laminæ consist of true vessels, which are derived from the exogenous ligneous zone.

But there is yet another peculiar lateral appendage found in this plant, as seen in a transverse section of a stem represented in Plate XXIII. fig. 7. In the centre of this figure we observe that the vascular laminæ bounding two of the medullary rays are forced asunder, to permit the escape of a large mass of tissue (*n*), some of which emanates from the left-hand ray, but the greater portion of it comes from the one to the right. It will be observed that in this instance there is no disturbance of the regular order of the vascular laminæ of the exogenous zone beyond their being thrust asunder at their peripheral margins; neither is there the slightest indication of what appears obvious in Plate XXVI. fig. 24, viz. a direct connexion between the vascular tissues of the parent axis and those of the branch. As the latter proceeds outwards, it passes through the parenchymatous (*h*) and prosenchymatous (*k*) layers of the bark, contracting rapidly in diameter as it does so, and terminates abruptly at the circumference of the outer bark (*n'*).

Unlike the previous examples, this divergent structure consists of a mass of cells, many of which are so elongated and fusiform as to assume a pseudo-vascular aspect. But each cell and pseudo-vessel, unlike the cells of the parent medulla and medullary rays, is beautifully reticulated like the true vessels of the central axis—an important feature to be borne in mind on endeavouring to assign a probable function to this organ. Equally important is it to remember that the tissues composing this appendage, instead of being derived from the vascular laminæ forming the two lateral boundaries of one medullary ray, have every appearance of originating in some metamorphosis of the mural cells of two such rays. We can clearly trace the pseudocambial layer of the parent axis accompanying the above structure in its outward course in the shape of an investing cylinder.

It thus becomes clear, not only from the specimens described, but from other similar ones in my cabinet, that though we discover no true dichotomization or *externally* conspicuous branching of the *Dictyoxylon*-stems, they gave off distinct lateral appendages almost at right angles to the axis of the parent stem. What were these diverticula? whither did they go? and why do they terminate so invariably at the circumference of the parent bark?

I think we must separate Plate XXIII. fig. 7, *n*, from the other examples; it differs alike in its structure and origin. My impression is that it may have supplied an adventitious or aërial root, which impression is confirmed by the history of a similar appendage which I find in *Dictyoxylon Grievii*. The other examples in which we have a distinct central axis surrounded by a regularly constructed exogenous zone are manifestly young branches; but whether they were prolonged into ordinary leaf-bearing branches, or whether they were half-abortive fruit-bearing ones, I am unable to determine. The invariable absence of any outward prolongation of them beyond the periphery of the parent stem, certainly seems to indicate a connexion with some deciduous appendage. Had they been prolonged into such persistent organs as true branches, it is difficult to believe that clear proof of the existence of such organs would not have been met with in some example amongst the hundreds of these stems which I have examined.

That they were not the vascular axes of leaf-petioles seems clear from their exogenous organization. I know of no leaf, however large, in which such an organization exists. Hence, as already suggested, I am inclined to believe that they may have nourished spikes of fructification, which, being modified branches, might be expected to retain a branch-structure in their central axes. I have shown in my last memoir the existence of exogenous layers in the axis of a *Lepidostrobus*, and I have in my cabinet specimens of *Volkmannia Binneyi* which have a similar radiating external woody cylinder. Hence there is no impossibility involved in the supposition that similar conditions may have prevailed in *Dictyoxylon*. These, however, are purely hypothetical suggestions; and the further fact remains, that we have hitherto discovered no fruits that could, with reasonable probability, be correlated with the stems in question.

Whatever may have been their functions, these branches throw a clear light upon the origin of the irregular vascular medullary cylinder seen even in very young Dictyoxylons, and which only remain, in a fragmentary state, as detached buttresses supporting the inner surfaces of the exogenous woody zones. But we must further study this subject in the light of the facts described in my last memoir on Lepidodendroid plants. I there showed that the compact central vascular axis of each young Lepidodendroid twig first expanded into a vascular cylinder, through the rapid fusion and multiplication of some of the more central cells located amongst the vessels, and which thus developed into a true cellular medulla, the growth of which was synchronous with that of the vascular cylinder. I further demonstrated that this compound axis became invested, at a still later period, by a true exogenous ligneous zone. It appears to me that corresponding phenomena reappear in the Dictyoxylons, but with some characteristic differences. In the Lepidodendroid plants each vasculo-medullary axis expanded into a regular cylinder, whose walls were of almost uniform thickness throughout its entire circumference, and which permanently retained its integrity throughout the life of the plant. In *Dictyoxylon* the solid vascular axes of Plate XXV. fig. 16 & Plate XXVI. fig. 23 expanded in like manner, and also had a cellular medulla developed within each cylinder; but the thickness of the latter was not only unequal in its various parts, but, at a very early period, it broke up into several detached and irregular masses, which no longer effected a complete separation of the pith from the exogenous layers throughout the entire circumference of the former organ. In the intervals between these detached vascular masses the cells of the medulla, and those of the medullary rays, become continuous with one another. In the first instance each radiating exogenous lamina had its inner margin in direct contact with the medullary vessels: this is indicated clearly in such specimens as that represented in Plate XXII. fig. 3. But though the disruption of the cylinder ultimately limited this direct cohesion of the exogenous with the medullary vessels to certain well-marked clusters of the former, evidence of similar but earlier relations of the entire ligneous zone is retained in the curvilinear forms of many of the woody wedges, whose inner margins are now in direct contact with the medulla; as in fig. 3, their several medullary extremities still bend towards the nearest cluster of medullary vessels with which they were, at an earlier period of their growth, in direct contact.

I have already called attention (in page 383) to the relations which these detached medullary bundles sustained to those lodged in the inner bark, and pointed out the way in which the latter helped to equalize the resisting power of the compound vascular cylinder, by strengthening those parts of the woody zone which were weakened by the breaking up of the medullary cylinder. This idea receives confirmation from the fact that, so long as the central axis is occupied by an undivided vascular bundle, these cortical buttresses are invariably wanting. In no one of the lateral diverticula which I have just described, and in which the *solid* axis invariably existed, did I find a trace of these cortical bundles: all the facts indicate that they were growths developed in the bark at a later date; at the same time such specimens as the original of Plate XXII. fig. 2 showed that they became fully grown before the disruption of the medullary cylinder had proceeded to any considerable extent.

The large size of the medullary rays, and the simple and conspicuous organization of the woody wedges in *Dictyoxylon*, enable us easily to compare its growth with that of living Dicotyledonous stems. As in the latter instances, we find that, as the wedges extended themselves in the peripheral direction, they became enlarged transversely by the addition of new laminæ. This was sometimes the result of two meristem-cells occupying the place previously filled by one, the consequences of which are seen in the conversion of the single lamina into a double one, as in Plate XXII. fig. 3, *e*. In other instances new and very small laminæ were either intercalated into the substance or added to the external surface of each wedge. Examples of all these methods of growth abound. If not antagonized, the continuance of this process would have given the peripheral portions of the wedges very different dimensions to those described in the preceding pages. I have already pointed out that we rarely find a dozen laminæ in any one wedge. The constant intercalation of new secondary medullary rays which took place here, as in living exogens, produced the result described. We thus see that in many of its minute details, as well as in its more general aspects, the growth of these stems has been a truly exogenous one.

The bark of one specimen, but which stands alone amongst the number of those that I have examined, exhibits conditions requiring further elucidation: I am as yet unable fully to understand its significance, but it is suggestive of additional facts belonging to the history of *Dictyoxylon* that have not yet been worked out. In this specimen, part of which is represented by Plate XXVI. fig. 25, we have the exterior of the ligneous zone at *d*. Some very slight traces of the parenchymatous layer of the bark are to be seen investing the woody zone. On the other hand, the prosenchymatous layer (*k*) is very thick: this thickness is due to the appearance of a large double vascular bundle, surrounded by a considerable mass of parenchyma, which is lodged in the substance of the prosenchymatous layer. Two of the vertical prosenchymatous laminæ, seen at *k'*, *k'*, have obviously been pushed aside to make room for the above intrusive structure. I have already mentioned the fact that I have never seen any of the cortical bundles located in the prosenchymatous zone of the bark, save in one solitary instance, the latter reference being to the example now under consideration. The double vascular mass (*z*) bears so striking a resemblance to these bundles when but partially divided, as to leave little doubt that it is really one of them. At the first glance we might suppose that it had been accidentally displaced from its normal position and forced, by pressure, into the outer bark; but such is certainly not the case. The parenchyma with which it is surrounded is identical with that separating all the prosenchymatous laminæ, leaving little reason to question that one of the parenchymatous areolæ of the outer bark has been specially enlarged to admit of the outward transmission of the vascular bundle and its thick parenchymatous investment, the vertical prosenchymatous layers (*k'*, *k*) having been thrust apart to make room for this enlargement and transmission.

These conditions suggest the possibility that others of the cortical bundles may finally leave the woody zone and pass outwards to supply foliar appendages with vascular tissue. The large size of these bundles indicates (supposing the above suggestion to be correct) that the missing appendages have been of corresponding dimensions. They suggest fronds rather than leaves. It is impossible to reason upon such limited data with any confidence; but I shall recall attention to the facts just described when I proceed, on some future occasion, to examine the stems or petioles to which I have proposed to assign the provisional name of *Edraxylon*[*].

---

[*] Proceedings of the Royal Society, vol. xx. p. 438 (1872).

Our history of what is known of this remarkable plant is not yet exhausted. On examining the fine series of coal-plants in the Liverpool Museum, which owes so much to the ever-vigilant energy of the Rev. H. H. Higgins, of Rainhill, I detected a series of cortical impressions which evidently belonged to an arborescent tree, and which I at once identified as having a probable relationship to my Dictyoxylons. On naming this circumstance to Mr. Carruthers, he called my attention to the fact that a specimen similar to the Liverpool ones had been described by the late Mr. Gourlie, of Glasgow, under the generic name of *Lyginodendron*. Dr. Bryce, of Glasgow, kindly furnished me with Mr. Gourlie's memoir, which at once satisfied me that the Liverpool specimens were varied forms of the *Lyginodendron Landsburghii* of the Scotch author. Mr. Gourlie gave a characteristic figure of his fragment in the 'Proceedings of the Philosophical Society of Glasgow' for February 15th, 1843, but he made no attempt to describe it scientifically, or to correlate it with any other known fossil plants. He obtained the fragment from the Rev. David Landsborough, and having recognized that it was undescribed, he contented himself with figuring it and giving to it the above name. On turning to Corda's 'Beiträge zur Flora der Vorwelt,' published two years later, I found a fragment of the same kind figured under the name of *Sagenaria fusiformis* (*loc. cit.* Taf. vi. fig. 4). Corda brought together in his plate, along with this specimen, fragments of a true Lepidodendroid bark, with some other plants showing internal organization; but I am perfectly satisfied that fig. 4 of his plate, the *Lyginodendron* of Gourlie, has no relationship whatever to the objects associated with it.

Plate XXVII. fig. 26, which bears the closest resemblance to Mr. Gourlie's specimen, consists of a slab of sandstone whose surface is covered with oblong-fusiform elevations of variable dimensions; the largest of these are fully three inches in length and nearly half an inch in diameter. As shown in the figure, these elevated areolations are in close contact with each other, being merely separated by a sharply defined groove, their surfaces being rounded or slightly flattened. Plate XXVII. fig. 27 represents a similar specimen, only in this example the largest areolæ are rarely more than 2 inches in length and ·18 in breadth; they are more uniform in size and regular in their arrangement than in fig. 26, exhibiting a greater tendency to dispose themselves in the oblique spiral lines of the Lepidodendroid plants than in the other specimen; the surface of each areola also projects in a sharp, central, longitudinal ridge. In Plate XXVII. fig. 28 we have a third modification. In this example the areolæ rarely exceed 1·5 in length and ·12 in diameter, whilst they are separated from each other by flat spaces from ·2 to ·1 in breadth. Their surfaces in this instance likewise are more or less rounded. Plate XXVII. fig. 29 is a small specimen, also with convex areolæ, which are very uniform in size and contour, as well as regular in their Lepidodendroid arrangement; as in the last figure, flat areas intervene between the fusiform areolæ.

In a fifth specimen of this instructive series the areolæ are not more than an inch in length, whilst in a sixth they are reduced to about half that size. Plate XXVII. fig. 28 is a flat fragment fully 7 inches in diameter; and even the sixth example just referred to is nearly $2\frac{1}{2}$ inches in breadth and perfectly flat. Hence it is obvious that all these specimens belonged to stems or branches of arborescent dimensions, whilst the successive gradations in the size of their areolæ clearly indicate that their differences are merely those of age and growth. Specimens in my own cabinet, and a sharply defined one in that of Mr. BOYD DAWKINS, link the above series with those described in the preceding pages, leaving no room for doubting that the whole belong to one form of vegetation, of which the larger examples were casts of the bark of the arborescent stems, and the smaller ones, in which the entire organization is preserved, the peripheral extremities or branches. The explanation of these casts is sufficiently obvious. The fibrous bands, forming a coarse network in Plate XXIV. figs. 13 & 15, have constituted a firm framework, alike resisting atmospheric abrasion and contraction through desiccation. The enclosed cellular areolæ have been characterized by precisely opposite features. Hence, where the latter reached the surface of the bark, deep lenticular depressions presented themselves, whilst the surrounding fibrous bands stood up in bold relief. That these results were partly due to the shrinking of the cellular areolæ is shown by two specimens in my cabinet: they both consist of the usual prosenchymatous bark of branches in which the inner or parenchymatous layer has been replaced by inorganic matter; but the *inner* surface of the *outer* bark exhibits precisely the same areolation, save that the concavities of the areolæ are now directed *inwards* instead of *outwards*, that I have just described as characterizing the periphery of the same bark-layer. The difference in the relative size of the areolations and of the intervening flat spaces in Plate XXVII. figs. 26 & 28 has obviously been due to corresponding differences in the thickness of the raised fibrous bands in relation to the size of the cellular areolæ which they enclosed. We thus learn that whilst *Lyginodendron* is undoubtedly an inorganic cast of the prosenchymatous layer of the bark of *Dictyoxylon*, it may either represent its exterior surface, which has impressed its contour upon the surrounding mud or sand, or it may represent its inner surface, to which the inorganic material has obtained access through the accidental destruction of the inner parenchyma of the bark. Combining these observations with the evidence derived from Mr. NIELD's large specimen of the ligneous zone of *Dictyoxylon Oldhamium*, described on page 386, we are irresistibly brought to the conclusion that *Dictyoxylon Oldhamium* was an arborescent tree, which, from the comparative abundance of its fragments preserved in the Lower Coal-measures of Lancashire, must have formed one of the most conspicuous features of the forests of the Carboniferous age.

The bearing of the facts just recorded upon nomenclature will be considered after describing the next subject of this memoir.

In the spring of 1871, Dr. DAWSON, of Montreal, conferred upon me the double favour of directing my attention to the plants of Burntisland, and of introducing to me their energetic discoverer, G. GRIEVE, Esq. I soon found amongst the rich treasures which that gentleman had brought to light a most remarkable plant, closely allied in many points of its structure to *Dictyoxylon Oldhamium*. I gave a very brief and hasty description of this plant at the Edinburgh Meeting of the British Association, assigning to it the name of *Dictyoxylon Grievii*, after its discoverer. Since that period I have made numerous additional sections of the plant, some of which I will now proceed to describe. At the first glance no two plants could well appear to be more distinct than the two just named; it is only when we compare the details of their organization that we learn how numerous and strong are their points of affinity, and how great the amount of light which each throws upon the other. The example now under consideration always appears in the form of straight, slender, unbranched stems; but we also find associated with it much smaller twigs, having the characteristic structure of the larger ones, but with distinctive features in their central vascular axes, similar to those which distinguish a twig of a Lepidodendroid plant from its matured Diploxyloid stem.

Plate XXVIII. fig. 30 represents one half of a transverse section of one of the more matured of the stems that have hitherto been met with. We here readily discern a large vasculo-cellular medullary axis (*a*), a very thin investing ligneous cylinder (*d*), a thin and delicate inner layer of bark (*g*), a thick parenchymatous bark-layer (*h*), and a well-defined outer or prosenchymatous layer of the same (*k*).

The central axis consists of a mass of medullary parenchymatous cells, dispersed throughout which are numerous well-defined bundles of reticulated vessels, unprovided with any special sheaths. The cells have thin walls, and are devoid of all fibrous deposits in their interiors. Plate XXVIII. fig. 31 represents an enlarged portion of this medullary axis: the cells (*b*) are at once distinguished from the vessels (*c*) by their smaller size, their thinner walls, and their brown colour. The last distinction is an evidence, were such needed, of their cellular character: however thin the section, owing to their small size, we always look through one or more of their carbonized cell-walls; whereas the long tubular vessels, being filled by infiltration with pure carbonate of lime, and having their oblique transverse divisions only at long distances from each other, their transverse sections transmit pure white light. The relations of the cells and vessels are further shown in the longitudinal sections (Plate XXIX. figs. 32 & 33, *b* & *c*). Fig. 33, *b*, especially exhibits the aspect of these cells in vertical sections. The largest of them rarely exceeds ·0025 to ·0028 in diameter, and many of them are much smaller. The vessels are arranged in clusters, transverse sections of no two of which exhibit the same shape; and they are equally variable in the number of their component vessels. They are of large size, many of them being ·0052 in diameter; but they are frequently much smaller than this, and at the peripheral portion of the medullary axis they are invariably so. In the latter case, in the transverse sections, they are only distinguishable from the surrounding cellular tissue by their colour and their thicker walls. The clusters of the periphery also contain a larger number of vessels, as well as display a greater tendency to an irregular coalescence of the groups, than is the case nearer the centre of the axis. Plate XXVIII. fig. 34 exhibits the lateral aspect of one of these vessels, enlarged 200 diameters. The entire diameter of the medullary axis in the larger specimens is about ·13. This axis is invested by an exogenous layer of vessels (*d*), disposed in radiating lines widely separated by large medullary rays. The entire thickness of this zone is small, rarely exceeding

·025, which is its thickness on the upper side of the specimen figured, whilst on the lower one it contracts to ·008. This inequality in the thickness of the ligneous zone on opposite sides of the stem is an almost invariable characteristic of this plant. In some specimens the zone is of such small dimensions as to be easily overlooked by observers ignorant of its aspect in more developed examples; where such is the case, the vessels are also of much smaller size than elsewhere. The largest vessels are always found in the thickest part of the zone: here they frequently reach a diameter of ·0032; but in those parts where the zone is dwarfed their diameter does not usually exceed ·0017. In the case of the thicker laminæ, one or two of the innermost vessels are always smaller than the more peripheral ones. Whilst many of these vessels are reticulated, like those of the medullary axis, others are frequently scalariform: the latter is especially the case with those nearest the medullary axis. The radial section, Plate XXIX. fig. 33, partly traverses the outer part of the medullary axis (*b* and *c*), and partly the ligneous zone (*d*). The vessels (*d*) belong to the latter; and at *f*, *f* we have two medullary rays, the cells of which are of the mural type of parenchyma, being repetitions of what we found in *D. Oldhamium*, except that the transverse diameter of each ray is less in the present case than in the Lancashire species, though relatively large in proportion to the thickness of the entire ligneous zone. The latter has evidently been of a very lax character, differing materially in this respect from that of *D. Oldhamium*: I have never counted more than a dozen vessels in each of its radial series. At their inner margins the laminæ are usually connected with some one of the numerous peripheral clusters of medullary vessels; they very rarely, if ever, commence amongst the medullary cells. I shall shortly call attention to some curious clusters of vessels that occasionally interrupt the continuity of this ligneous zone. Plate XXIX. fig. 33 *a* represents a tangential section of this radiating zone. The medullary rays (*f*) are here seen to consist chiefly of a single vertical series of cells, and are further remarkable for the long vertical range of each ray. The figures and descriptions already given apply to the stems of this plant in their normal state; but it is only in rare examples that we meet with them in this undisturbed condition. The physical circumstances that have attended their mineralization have usually compressed and displaced the tissues in so great a measure that it becomes almost impossible to make out the structure of such specimens. The vessels have lost their cylindrical character, and the entire vascular axis is distorted into a confused mass of cells and vessels.

The bark of this plant is as interesting as it is remarkable; but I have found the minute interpretation of its varying aspects a difficult task, owing to the effects of the pressure alluded to in the last paragraph. The general outline of the plant is never the same either in different stems, nor even, as shown on Plate XXX., in different sections of the same stem; and I have found it no easy matter to determine how much of this irregularity was due to pressure and how much to the original peculiarities of the plant. The broad features of the bark are sufficiently obvious: it consists of three very distinct layers, the innermost two of which contain a few large, vertically disposed vascular bundles. These layers present very different appearances when viewed in transverse and in vertical sections: in the former the outermost layer exhibits the greatest peculiarities of structure; in the latter the peculiarities are the most striking in the middle one. The innermost layer exhibits the same appearances in both sections. The latter (Plate XXVIII. fig. 30, *g*, & Plate XXIX. fig. 35, *g*) exhibits so close a general resemblance to the innermost bark-layer of the Lepidodendroid plants, that I do not hesitate to assign to both the same functions. It has a rather uniform thickness of ·008, occasionally swelling out to as much as ·025. It consists of delicate parenchyma, the largest cells of which range between ·0023 and ·0028, their size being moderately uniform: sometimes they are arranged in radiating lines; at others they appear as regular parenchyma. This layer is a very distinct one, both in the definiteness of its boundaries, in the delicacy of its texture, and in the general uniformity of its aspect: in Plate XXVIII. fig. 30 it is seen describing a semicircle at *g g*, and in the vertical section at Plate XXIX. fig. 32, *g*. In every one of the numerous examples which I have examined, this inner bark appears too large for the cellulo-vascular axis which it invests. Sometimes the excess projects at one or both ends of the compressed axis, enclosing a vacant space, as in Plate XXVIII. fig. 30 & Plate XXX. fig. 36; at others it appears in the transverse section as a caudate appendage, occupying the same position as in most of the figures on Plate XXX. This condition has doubtless resulted from a contraction of the central axis that had no existence during the life of the plant. The layer has evidently been at once flexible and firm; since, though compressed into innumerable forms and detached from the central axis in a variety of ways, I have rarely seen its continuity interrupted, save where some vascular bundle passed through its tissues to reach the periphery of the stem.

The middle bark-layer (Plate XXVIII. fig. 30, *h*, & Plate XXIX. figs. 32, *h*, & 35, *h*) is a much more variable one. It consists of masses of very regular parenchyma, intermingled with horizontal layers of darker-coloured cells, which latter constitute the characteristic feature of this tissue. In transverse sections we only detect these darker layers in the form of dark isolated patches (Plate XXVIII. fig. 30, *h*′) and wavy lines (Plate XXIX. fig. 35, *h*′), surrounded by or enclosing clearer spaces occupied by regular parenchyma (Plate XXIX. fig. 35, *h*″); but in the vertical section the former appear in the shape of very regular, parallel, horizontally disposed bars (Plate XXIX. fig. 32, *h*′). The ordinary parenchyma consists of cells having a maximum diameter of from ·0028 to ·004. In Plate XXXI. fig. 45, which represents this tissue in a vertical section of the two outermost layers of the bark of a very young stem, each cell has been drawn with scrupulous accuracy, the dark-coloured transverse bars being represented at *h*′ *h*′, and the intervening parenchyma at *h*″. In vertical sections of this tissue in older stems the latter cells constantly exhibit a disposition to arrange themselves in vertical and often slightly curved lines (Plate XXIX. fig. 32, *h*″), approaching, in the former respect, to the condition of the tissue so common in the medullæ of the Lepidodendroid plants*.

---

* Mr. Binney has proposed ("Observations on the Structure of Fossil Plants found in the Carboniferous Strata.—Part III. *Lepidodendron*") to assign to this tissue the name of "orthosenchyma." It is but one of the

Plate XXXI. fig. 45 exhibits correctly the general aspect of the dark coloured horizontal bands, and their relations to the intervening layers of ordinary parenchyma. The cells of the former are smaller and more uniform in size, as well as less lax in their arrangement, than the latter. The bands are arranged at uniform distances, which vary little in different specimens, there being generally about forty-six of these in each vertical inch. They do not appear to form absolutely continuous rings in matured examples, encompassing the entire stem, though they do so in young shoots. In the former case they are frequently interrupted by the vicinity of cortical vascular bundles; but, in addition to this, we observe often in vertical sections the faintly defined margin of one of these bands intercalated between two sharply defined ones, indicating that some of them at least become merged laterally in the surrounding parenchymatous tissue: tangential sections of the same structure also frequently indicate that where a cortical vascular bundle approaches the outer bark, the dark bands of the parenchyma right and left of the bundle are alternate in their arrangement rather than continuous.

The "orthenchymous" disposition of the parenchymatous cells is sometimes seen in transverse sections, as in Plate XXVIII. fig. 30, *h*″; but in these instances I have no doubt that the section has passed somewhat obliquely through the tissue in question.

I shall call attention to some further peculiarities in this parenchymatous layer when describing the vascular bundles (*m*) which traverse it.

The outermost layer of the bark (Plate XXIX. fig. 35, *k*) is also a well-defined one, which scarcely differs in its essential features from the prosenchymatous layer of *Dictyoxylon Oldhamium*. Its usual thickness is about ·021; but, as we shall immediately see, it is liable to undergo a sudden enlargement at special points. In the horizontal sections (Plate XXVIII. fig. 30, *k*, & Plate XXIX. fig. 35, *k*) it exhibits a radiating series of alternating bands of parenchyma and prosenchyma, the former being light-coloured and semitransparent, and the latter of a denser texture and a darker hue—conditions which are identical with those seen in the corresponding layer of *D. Oldhamium* (Plate XXIV. fig. 10). The prosenchymatous fibres have a diameter of about ·0005, occasionally expanding to ·001.

In radial vertical sections (Plate XXIX. fig. 32, *k*″, & Plate XXXI. fig. 45, *k*) the cells of this layer appear in the two forms of prosenchyma and of elongated parenchyma of the prismatic cylindrical variety with square ends. In tangential sections these tissues are arranged in the same way as in *D. Oldhamium*, viz. the prosenchymatous bands form a network enclosing vertically elongated parenchymatous areolæ of a lenticular form. But the plant under consideration differs from the Oldham one, so far as this portion of the bark is concerned:—1st, in the greater relative thickness of the prosenchymatous bands; and, 2nd, in the smaller size and almost linear vertical form of the enclosed areolæ. A

---

innumerable modifications of parenchyma and frequently seen amongst living Cryptogams; but if we do give it a special name it must be "orthenchyma." Mr. Binney's term involves an impossible, *i. e.* an ungrammatical, combination of noun and adjective; besides which mine is shorter, and accords better with its similar modifications of Bothrenchyma, Orthanthera, &c.

further difference is seen in the entire absence from *D. Grievii* of all trace of the thin outermost or subepidermal layer of parenchyma which occurs in young shoots of *D. Oldhamium*.

Vascular bundles.—I have already alluded to the existence in the bark of large bundles of vascular tissue, which ascend vertically through the stem. In transverse sections these bundles exhibit a more or less oval section (Plate XXVIII. fig. 30, *m m'* & *m''*, & Plate XXIX. fig. 35, *m* & *m'*), the longer axes of which are parallel to radial sections, or to the circumference, of the bark. Most of these bundles exhibit some tendency towards a division into two lateral halves, either in a median constriction of their peripheral outline (Plate XXIX. fig. 35, *m'*), in a disposition of the component vessels to group themselves round two determinate centres (Plate XXVIII. fig. 30, *m'*), or in an actual line of demarcation dividing the bundle into two parts. These bundles chiefly consist of barred vessels, with some reticulated ones, imbedded in a mass of small cells identical in size, colour, and general aspect with those of the medullary axis. Under a high magnifier these cells can generally be traced between the two divisions of the vascular bundle. No part of this investigation has caused me such serious trouble as that relating to these bundles. It was easy to see that they *most probably* originated somehow in the vascular axis, and that they proceeded outwards towards the periphery to supply leaves or fronds. The difficulty was to obtain proof of all this, owing to the circumstance that a large number of longitudinal sections threw little light upon the matter. The bundles were present in the sections; but, owing to their small size and want of perfect straightness in their course, I could not trace that course over any considerable area; whilst, so far as I was able to do so, I obtained but few and faint evidences of divergence from parallelism with the central vascular axis. At last, having obtained a favourable specimen, nearly two inches in length, I made, at measured intervals, the series of eight transverse sections represented in Plate XXX. figs. 37–44. These sections gave me the key to the history of this portion of the plant.

We sometimes find these bundles inside the innermost cylinder of bark-cells, as in Plate XXVIII. fig. 30, *m*, and partially in Plate XXIX. fig. 35, *m*. In the latter instance the bundle is almost imbedded *in* this bark-tissue, a condition not unfrequently met with. They further occur in all parts of the middle parenchymatous layer, but never in the prosenchymatous one. So far as I can ascertain, the number of these bundles, in a perfectly free state, in any one transverse section is usually seven or eight, the latter being the largest number that I have yet seen. In the sections represented on Plate XXX. we find only six; but the specimen was imperfect at one side, and one or two bundles doubtless disappeared in the missing portion. Of these sections, I believe fig. 37 to belong to the lower, and fig. 44 to the upper extremity of the fragment; at all events such has been the case if, as I expect, the bundles have supplied leaves and not roots.

In the figures of these sections I have not filled in the details of their organization, but the outlines of the various structures have been drawn to the same scale and with the utmost attention to accuracy of measurement. In each of them *a* represents the medullary vasculo-cellular axis, *g* the pseudocambium or innermost bark, *h* the parenchymatous bark, and the dark shaded outline, *k*, the peripheral prosenchyma. Six vascular bundles are indicated by corresponding numerals, the same numeral being attached to the same bundle in each section. We thus see that in Plate XXX. fig. 37 there is one bundle (3) enclosed *within* the innermost bark; 1, 4, and 6 are external to, but in almost immediate contact with, its outer surface; whilst 2 and 5 are in the parenchymatous layer at a little distance from the pseudocambium. Bundle 1 retains its unchanged position in all the sections up to fig. 42; in each of the remaining two the section is imperfect, and this bundle has been lost. Bundle 2, on the other hand, is seen in all the sections; but it also occupies nearly the same position in fig. 44 that it does in fig. 37, as well as in the intermediate ones. Bundle 3 first appears in fig. 37 enclosed within the pseudocambium layer, but entirely separated from the vasculo-cellular medullary axis: in fig. 38 it is imbedded in the substance of the inner bark; in fig. 39 it has escaped through that innermost bark-layer, and now rests upon the outer surface of it; which position it retains undisturbed up to the uppermost section, fig. 44. Bundle 4 occupies the same unaltered position throughout the entire series. The same remark applies to bundle 6 in the first six sections, in which it is present, it having disappeared from figs. 43 & 44, from the same cause as that which has removed bundle 1. Bundle 5, on the other hand, not only appears in all the series, but has undergone important alterations of position in the interval separating figs. 37 & 44. Following these sections in their numerical order, we see that this latter bundle has moved steadily outwards, until in fig. 43 it only appears as a semidisorganized mass external to the prosenchymatous layer of the bark.

We further learn that the changes in the position of the latter bundle have been accompanied by some correlate changes in the bark itself. In Plate XXX. fig. 37 the prosenchymatous layer of the bark external to bundle 5 is rather thinner than usual, forming a conical protuberance which projects slightly beyond the general peripheral outline of the stem; at the base of the conical portion a prolongation of the prosenchyma extends obliquely inwards to the right, whilst the same layer is also somewhat thickened on the left hand of the apex of the cone. As we proceed towards fig. 40 we find that the prosenchyma to the left hand of the bundle gradually thickens, until it forms a prominence which projects inwards, precisely like that already noticed as existing to the right of the bundle in fig. 37. In fig. 41 we discover that the bundle is fairly within a circumscribed area, which resembles in form a section of the base of a Lepidodendroid leaf. In fig. 42 the bundle has reached the centre of this area, besides which the outermost bark (*k*) immediately external to the bundle is now becoming disintegrated. In fig. 43 the process has gone still further. The half-decomposed bundle can now scarcely be identified, encompassed as it is, in the original section, by the foreign vegetable *débris* which surrounded the entire stem. The thin bark-layer (*k*) seen in fig. 42, has wholly disappeared, and the two projections of the outer bark (k' k') are rapidly converging to produce that complete closure of the interruption to its continuity which is seen in fig. 44.

If we now turn to bundle 2 and interpret it by the light afforded by the preceding description, we shall see that it is about to undergo similar changes. The bundle itself exhibits little change of position in the several sections, but the prosenchymatous bark has altered its form so that the bundle is in nearly the same condition in fig. 44 that bundle 1 exhibits in figs. 38, 39, & 40. We here learn several important facts. The first is that whilst the vascular bundles retain the same unchanged positions throughout a considerable length of the stem, they each in turn move outwards and disappear at the periphery of the bark: the second is that the irregularities in the outline of the bark are not wholly due to external pressure, but to the successive development of a series of peripheral appendages, the bases of which have risen from the bark in the form of sharp, projecting, longitudinally disposed ridges with broad bases. During the progress of these changes we always find that, immediately external to each vascular bundle, the parenchymatous layer of the bark consists of a large mass of very regular and translucent parenchymatous cells, as represented in Plate XXIX. fig. 35, h'', and an expansion of which tissue has evidently constituted the great bulk of the appendicular organ, whatever it was, since similar masses of parenchyma retain the same position in the enclosed areas external to bundle 5 in Plate XXX. figs. 41 & 42. I do not doubt that all the lenticular areas of regular parenchyma (Plate XXX. figs. 37, h', & 41, h') enclosed within lines of more condensed cellular tissue were destined in turn to receive new bundles of vessels at points higher up in the stem.

I have no difficulty in determining whence these bundles were derived. I have called attention to the coalesced clusters of small vessels which occupy the peripheral portion of the vasculo-cellular medullary axis immediately within the exogenous layer. Small masses of these clusters, consisting of vessels intermingled with medullary cells, first become isolated, and then tend outwards, emerging through the exogenous zone, as in Plate XXVIII. fig. 30, m''', the exogenous radiating laminæ becoming separated to allow of their escape. On the opposite side of the figure just quoted, we observe a break in the continuity of the exogenous ring, from which vacant space a similar bundle has obviously emerged. Nearly every transverse section in my cabinet exhibits similar evidences that the bundles originated as I have just described. Before considering the probable significance of these growths, there remains to be noticed another peculiar, cylindrical, divergent appendage of a different kind, and which is represented in Plate XXX. fig. 36, n. It consists of a mass of cells and vessels, or rather pseudo-vessels, both equally reticulated, which appear to take their rise in the cellular portion of the vasculo-cellular medullary axis. I have not been able to trace any of the true vessels of that axis within the diverging appendage, though I cannot affirm that there is no connexion between the two tissues. At its base this large bundle has been about ·25 in diameter, but it soon contracts to ·12. The section having cut through it somewhat obliquely, its more central portion is seen in the specimen figured, and its peripheral extremity appears in a contiguous section made from the same specimen. By combining the two portions, we obtain a length of nearly half an inch. Arising, as described, in the central axis, it proceeds outwards, penetrating in succession the parenchymatous and prosenchymatous layers of the bark, but carrying the innermost pseudocambial layer (g) along with it in the form of an investing sheath (g'). At its outer extremity it terminates in a disorganized carbonaceous mass, which I am unable to interpret. The tissues of which this organ is composed remind us of the elongated scalariform cells or incipient vessels which form in the developing roots of Ferns and Lycopods. In this respect they also correspond with the similar appendage of *Dictyoxylon Oldhamium*, shown in Plate XXIII. fig 7, n'. The above is the only clearly defined example of this growth which I have seen in *D. Grievii*, but unmistakable indications of a similar structure appear in Plate XXVIII. fig. 30, n.

Associated with the ordinary stems of *D. Grievii*, I find abundance of small twigs of the same plant, a transverse section of one of which is shown in Plate XXVIII. fig. 46, and a longitudinal section of the same specimen is given in Plate XXXI. fig. 47. The former of these is precisely what the bundle 5 of Plate XXX. figs. 41 & 42 would be, supposing it could be prolonged upwards, with its investments of parenchyma and prosenchyma, until it projected clear of the parent axis. In the transverse section of each of these twigs we have a more or less triangular figure with prolonged lateral angles. The greater portion of this area consists of a mass of parenchyma (h), surrounding a vascular bundle (m): the latter consists of an intermingled cluster of barred and reticulated vessels—often separable into two groups, and imbedded in medullary parenchyma. This bundle is not placed in the centre of the twig, but excentrically, or nearer the slightly heart-shaped base than the apex of the triangular outline seen in the transverse section, the peripheral margin opposite to it being either rounded or projecting in an obtuse angle. The entire structure is invested by a thin layer of outermost bark (k), consisting of alternating bands of prosenchyma and parenchyma, like those of the parent stem. The thin lateral expansions of the twig are often doubled back upon the thicker central portion, as in Plate XXVIII. fig. 46. The position is an accidental result of pressure, but it indicates that these angles of the twigs projected like those of a petiole with decurrent leaflets.

On turning to the vertical section (Plate XXXI. fig. 47) we find a single central bundle (m) invested with a bark which presents, in an uncomplicated form, the essential features of that of the parent stem. We have here the three typical layers of the bark, only the inner bark is very feebly represented. It appears as a thin layer of delicate, vertically elongated cells, immediately surrounding the bundle; it is closely attached to the central vascular bundle opposite to each of the dark transverse bands of the parenchymatous layer, but bulges outwards in the intermediate spaces. The moulding effect of contact with this innermost layer is seen in the undulating outline of the left side of fig. 45, which only represents the parenchymatous and prosenchymatous layers of one of these young twigs. The parenchymatous layer corresponds with that of the larger stems, only each of the dark horizontal bands of cells (h') now extends continuously, in a quoit-like form, across the twig. The prosenchyma, *k*, is in all respects, except its thinner dimensions, like that already described.

Whatever these twigs may be, homologically, I have no doubt that they are the free prolongations of the lateral diverticula from the parent axis, described in pages 400 & 401. There can, I think, be little question that they are petioles rather than branches; but as yet I have not succeeded in connecting them with any thing resembling leaves. They bear so close a general resemblance to corresponding sections of the petioles of the *Lepidodendra* as to leave little room for doubting their petiolar character. If this be a correct interpretation, it follows that *Dictyoxylon Grievii* has been a stem giving off large foliar appendages, at somewhat distant intervals and from its entire circumference. That these appendages have been of considerable dimensions relatively to the diameter of the main stem, is indicated by the large size of each of the petiolar bundles of vessels. Whether it was an erect stem or a creeping rhizome is doubtful; but the circumstance that the exogenous zone is always so much thicker on one side than on the other, suggests the possibility of an excess of vital action on that side, due to the stimulus of light upon the upper surface of a creeping stem. Supposing this inference to be correct, the question recurs, What is the large divergent vascular bundle of fig. 36? Most probably the vascular bundle of a large adventitious root rather than a true branch. It bears a most striking resemblance to the bundles seen in corresponding sections of recent Lycopodiaceæ, which supply the roots or root-bearers; only in the latter case the vessels originate in the vascular bundles of the main axis. It bears a still closer resemblance to that of *D. Oldhamium*, seen in Plate XXIII. fig. 7, *n*. In both plants the reticulated vasculo-cellular mass appears to be projected from cellular tissues; only in *D. Oldhamium* the intervention of a thick ligneous zone shuts out the root-like organ from direct association with the pith, and compels it to spring from it indirectly through the cells of the medullary rays, whilst in *D. Grievii* it starts directly from the axial medullary cells.

The supposed petioles just described, whether we regard their structure or their probable origin as illustrated by Plate XXX. figs. 37–44, help to throw some light upon the very similar portion of *Dictyoxylon Oldhamium* represented in Plate XXVI. fig. 25. The latter bears strong indications of having been one of the double vascular bundles seen in the inner and middle layers of the bark, but which is here moving outwards to form, with its surrounding parenchyma, the base of a petiole. But if this has been the case, why are such examples so seldom met with? and where are the petioles which, considering how abundant *Dictyoxylon Oldhamium* is, cannot have been rare objects?

In the 'Proceedings of the Royal Society' (xx. p. 438) I have pointed out the existence, in the Lancashire nodules, of abundance of small stems or petioles, to which I gave the provisional name of *Edraxylon*. I have since succeeded in connecting these petioles with the leaflets of a *Pecopteris*. I think it far from impossible that these may prove to belong to *Dictyoxylon Oldhamium*; but since I have not yet succeeded in correlating them with any certainty, I shall add no more respecting them at present; the details of their curious organization will be made the subject of a future memoir. It follows from the previous determinations that the bark of *D. Grievii* is essentially a mass of coalesced petioles. The final question to be asked is difficult to answer. What are the mutual relations and botanical affinities of the two plants which I have described? That they possess many points of close mutual resemblance is obvious from the preceding descriptions, especially in their reticulated vessels, in the general aspects and arrangement of their cortical vascular bundles, in their root-like appendages, and especially in the structure of the parenchymatous portions of the bark. On the other hand, they exhibit some equally obvious differences, especially in the composition of the vasculo-cellular medullary axis and in the very different dimensions attained by their exogenous ligneous zones. There is now no room whatever for doubting that the *Lyginodendron* of Mr. GOURLIE is a sandstone impression of the exterior of the bark of a plant like *Dictyoxylon Oldhamium*, if it does not, as I think exceedingly possible, represent the arborescent condition of the same species; but since the latter point is not clearly established, it will be more prudent to retain, for the present, Mr. BINNEY'S specific name. On the other hand, my generic name of *Dictyoxylon* must clearly be abandoned for that of Mr. GOURLIE, so that the plant in question may henceforth be recognized as *Lyginodendron Oldhamium*. If at any future period specimens having the internal organization of our Oldham plant should be found at the Ayrshire district, whence the Rev. DAVID LANDSBOROUGH obtained his casts, it may then become necessary to adopt Mr. GOURLIE'S name of *Lyginodendron Landsburghii* in its totality.

In plate xvii. of his 'Flora der Vorwelt,' CORDA published sections of a fragment of a plant which he obtained from the Bohemian Coal-measures, and to which he gave the name of *Heterangium paradoxum*. This specimen only exhibited a small portion of the vasculo-medullary axis; but, so far as it goes, the structure which he figures and describes appears identical with the corresponding portion of my *Dictyoxylon Grievii*. Since no trace of the bark exists in his specimen, we cannot identify the species of the German botanist with the Burntisland plant. But I think there can be no doubt that the two objects are generically identical. This circumstance in some degree affects the question whether the two plants which I have just described should be united in one genus or separated into two. On this point I entertain serious doubts; but if the latter plan be adopted, then my *Dictyoxylon Grievii* must be recognized as *Heterangium Grievii*. By acting thus we not only create no new genus, but, by the extinction of my new term *Dictyoxylon*, actually reduce the existing number; hence, for the present, it may be desirable to adopt this plan. If further research should bring the two plants yet closer together, then Mr. GOURLIE'S, being the oldest of all these generic terms, must be adopted for both. The accident of CORDA'S introduction of a fragment of *Lyginodendron* amongst his figures, under the name of *Sagenaria fusiformis*, is so obviously a blunder, that this still more ancient generic term may be excluded from our consideration.

We must not forget that all these names are merely provisional ones. These and numerous other stems that are the subject of research doubtless belong, in most cases, to leaves that are already well known, and that have long ago received appropriate names, which names must be those permanently adopted whenever we ascertain the correlation of these *disjuncta membra*.

The question of the botanical position of both the above plants remains undecided, and I confess I shrink from arriving at a decision in the present state of our knowledge respecting them. If I succeed in establishing a connexion between the common Oldham plant and the equally common *Edraxylon*, then, strange as it may appear, the former will become an undoubted arborescent fern; at the same time it has many features of affinity with the Lycopodiaceæ that must not be overlooked. On the other hand, the Burntisland species looks more Lycopodiaceous than fern-like; yet it is very different from all the other Lycopodiaceæ of the Carboniferous age with which we are familiar. I confess I find an increasing difficulty in distinguishing between the fossil stems of Lycopods and of Ferns—a difficulty that increases rather than the reverse the more extensive my acquaintance with these fossil forms becomes. These objects differ from their diminutive recent allies in so many features of their internal organization, that structural differences, of which we avail ourselves amongst the living plants, wholly fail to help us in discriminating the fossil ones. Until we obtain more decisive evidence respecting the foliage of the two subjects of this memoir, I fear we must locate them amongst the miscellaneous objects which BRONGNIART brings together under the heading of "*Sedes incertæ*"*.

The two figures Plate XXXI. figs. 48 & 49 are scarcely restorations, because little is introduced into either of them the presence of which is not absolutely demonstrated in the preceding figures. They are therefore diagrams showing the bird's-eye view of the actual structure of these plants, rather than restorations. The various letters of reference attached to them respectively indicate the same structures and tissues as those employed in all the other figures.

I have again to acknowledge my obligations to my Oldham friends, Mr. BUTTERWORTH, Mr. NIELD, Mr. WHITTAKER, and Mr. ISAAC EARNSHAW, for the aid they have afforded me in keeping me supplied with an abundance of specimens for examination. Through Mr. NIELD'S invaluable aid I have obtained large supplies of the calcareous nodules in which the fossil plants are found; and every one of these nodules has been subjected to an exhaustive examination, lest any available fact of importance should escape my eye. In reference to the Burntisland specimens, all my great obligations are centered in GEORGE GRIEVE, Esq., whose persevering energy and kindness I have already recorded in previous memoirs, and who has continued to lay me under fresh obligations. I must also record kind assistance from the Messrs. PATTESON, the well-known marble merchants of Manchester, who have allowed me the gratuitous use of their labourers and mechanical appliances on several occasions, when such help has been of material value. To all these friends I can only return my cordial thanks for the aid they have so kindly rendered.

---

* More recent researches have rendered it increasingly probable that *Heterangium Grievii* is a true fern. If so, the exhibition in its vascular axis of a very rudimentary form of exogenous growth becomes a physiological feature of great interest.—Manchester, September 15th, 1873.

Description of the Plates.

Lyginodendron Oldhamium.

Plate XXII. fig. 1. Transverse section of a young stem with an exogenous branch emerging through the bark, magnified $4\frac{1}{2}$ diameters.
,, fig. 2. Medullary axis and inner part of the ligneous zone of a very young stem, magnified 40 diameters.
,, fig. 3. Segment of a ligneous zone with one of the detached vascular masses of the medullary axis, magnified 50 diameters.
,, fig. 4. Transverse section of the entire vascular axis of a young stem, with an external young and half-developed vascular layer; magnified 6 diameters.
,, fig. 4*. Reticulated vessel of the ligneous zone, magnified 200 diameters.
,, fig. 5. Transverse section of the cellular tissue of the medulla, magnified 150 diameters.
Plate XXIII. fig. 6. Segment of a transverse section of a young stem with a young exogenous layer of half-developed vessels, magnified 50 diameters.
,, fig. 7. Segment of a transverse section of a young stem, giving off a supposed root-bundle, magnified 50 diameters.
,, fig. 8. Tangential section of the ligneous zone, composed of a network of vessels and numerous medullary rays, magnified 70 diameters.
,, fig. 9. Radial section of part of a ligneous zone, with portions of two vascular laminæ (*e*), and one medullary ray composed of mural cells (*f*), magnified 70 diameters.
Plate XXIV. fig. 10. Transverse section of part of the bark, with its several divisions of innermost layer (*g*), parenchymatous layer (*h*), prosenchymatous layer (*k*), and subepidermal layer (*l*), magnified 50 diameters.
,, fig. 11. Tangential section of the ligneous zone, giving off a lateral branch: the section intersects the bark (*g*, *h*, and *k*) almost radially; *h*′, frequent patches of dark-coloured cells: magnified 6 diameters.
,, fig. 12. Portion of fig. 11, magnified 18 diameters.
,, fig. 13. Tangential section of the prosenchymatous layer of the bark, with its prosenchymatous bands and cellular areolæ, magnified 5 diameters.
Plate XXV. fig. 14. Tangential section of the prosenchymatous layer of the bark of a young stem, with a branch emerging through it, magnified 6 diameters.
Plate XXIV. fig. 15. Tangential section of the prosenchymatous layer of the bark,

showing the tubular fibres of the prosenchymatous bands, magnified 28 diameters.

Plate XXV. fig. 16. Tangential section of the middle cortical parenchyma of a large stem, giving off an exogenous branch, magnified nearly 20 diameters.

" fig. 17. Double cortical bundle of vessels imbedded in the innermost bark-layer with the exterior of the ligneous zone, magnified 30 diameters.

Plate XXVI. fig. 18. Cortical bundle of vessels from fig. 1, magnified 80 diameters.

Plate XXV. figs. 19 & 20. Cortical bundles of vessels, with peripheral exogenous growths, from the innermost bark-layer of fig. 1, magnified 80 diameters.

" fig. 21. Cortical bundle of vessels with wedge-shaped exogenous additions to its exterior surface and adherent to the ligneous zone, magnified 24 diameters.

Plate XXVI. fig. 22. The branch (y) of fig. 14, enlarged 60 diameters.

" fig. 23. Central vascular bundle, with some of the exogenous laminæ and medullary rays of the branch (x) of fig. 1, enlarged 100 diameters.

" fig. 24. Transverse section of part of a young stem, the ligneous zone of which is giving off an exogenous branch.

" fig. 25. Transverse section of the bark of a young stem, with a double vascular bundle escaping through the prosenchymatous bark, as if to reach a petiole; magnified 75 diameters.

Plate XXVII. fig. 26. Cast of the exterior of the bark of an arborescent stem.

" fig. 27. Cast of the exterior of the bark of an arborescent stem.

" fig. 28. Cast of the exterior of the bark of an arborescent stem.

" fig. 29. Cast of the exterior of the bark of an arborescent stem.

Heterangium Grievii.

Plate XXVIII. fig. 30. One half of the transverse section of a stem, magnified 22 diameters.

" fig. 31. Portion of the medullary axis of fig. 30, magnified 70 diameters.

Plate XXIX. fig. 32. Longitudinal section of the stem, magnified 24 diameters.

" fig. 33. Radial longitudinal section of the exogenous zone of fig. 30, with mural medullary rays, magnified 72 diameters.

" fig. 33 *a*. Tangential section of the exogenous zone, showing the medullary rays, magnified 75 diameters.

Plate XXVIII. fig. 34. Reticulated vessel, enlarged 200 diameters.

Plate XXIX. fig. 35. Segment of a transverse section of the bark, magnified 24 diameters.

Plate XXX. fig. 36. Transverse section of a stem, giving off a lateral pseudo-vascular bundle, probably supplying an adventitious root, magnified 6 diameters.

,, fig. 37.
,, fig. 38.
,, fig. 39.
,, fig. 40.
,, fig. 41.
,, fig. 42.
,, fig. 43.
,, fig. 44.

Successive series of transverse sections of one stem, about 2 inches long, showing the changes in the relative positions of the vascular bundles at various heights of the stem: magnified 10 diameters.

Plate XXXI. fig. 45. Vertical section of the middle and outer layers of the bark of a young twig, magnified 96 diameters.

Plate XXVIII. fig. 46. Transverse section of a young twig, magnified 24 diameters.

Plate XXXI. fig. 47. Longitudinal section of the twig fig. 46, magnified 24 diameters.

,, fig. 48. Restoration of the young stem of *Lyginodendron Oldhamium*, cut open to show the several structures.

,, fig. 49. Restoration of the stem of *Heterangium Grievii*, cut open as in fig. 48.

Throughout the entire series of the preceding figures, the same letters are employed to indicate what appear to be homologous tissues and organs. They are also employed, as far as possible, in the same way as in my preceding memoirs of this series.

a. Medullary axis.
b. Medullary cells.
c. Medullary vessels.
d. Ligneous zone.
e. Ligneous zone, vessels of.
f. Medullary rays of ligneous zone.
g. Innermost bark-layer, parenchymatous.
h. Middle bark-layer, parenchymatous.
k. Prosenchymatous bark.
l. Subepidermal parenchyma.
m. Foliar (?) bundles of vessels.
n. Root-bundles ?
x & *y.* Branches.
z. Stem-bundles.

Fig 1

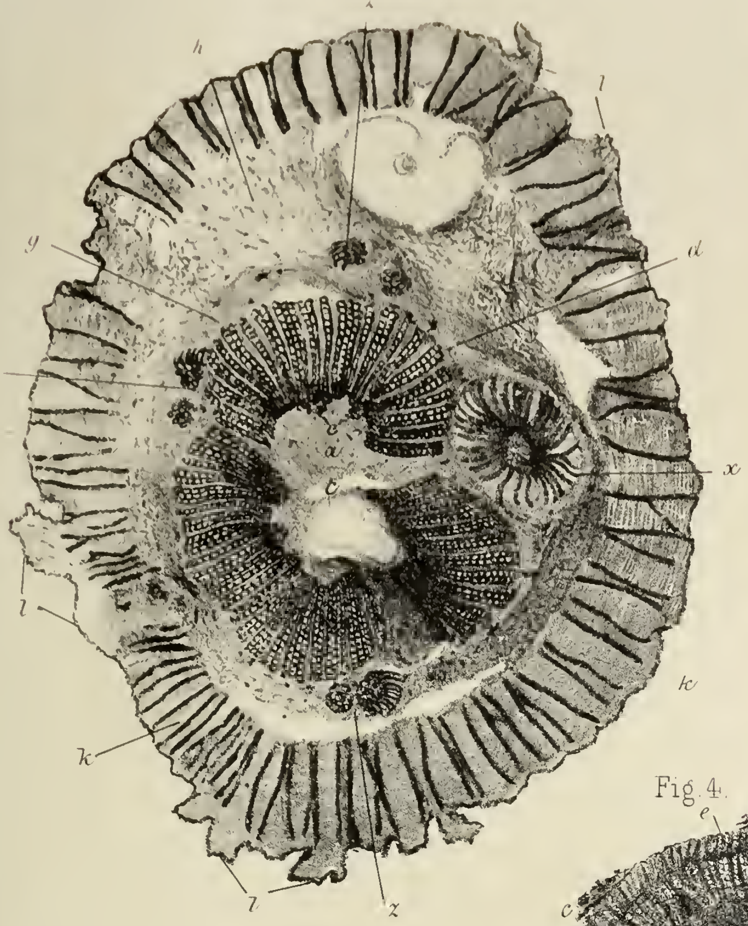


Fig 2

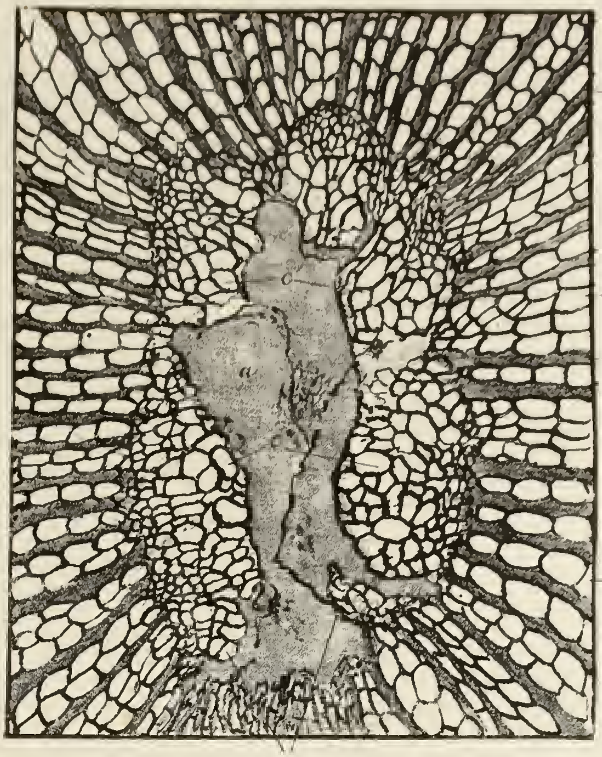


Fig. 4.

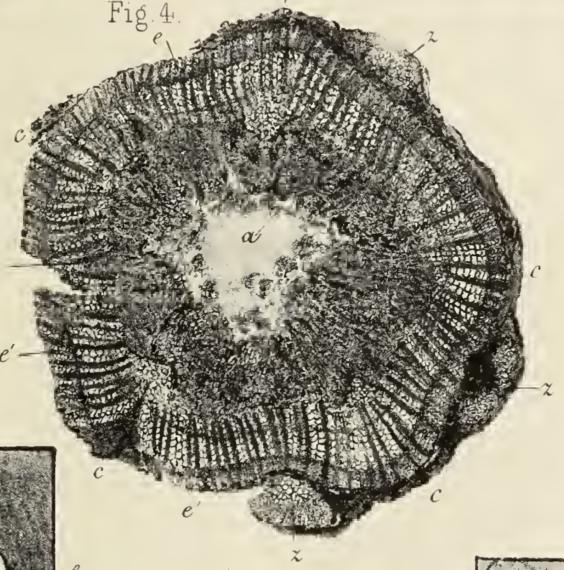


Fig. 3.

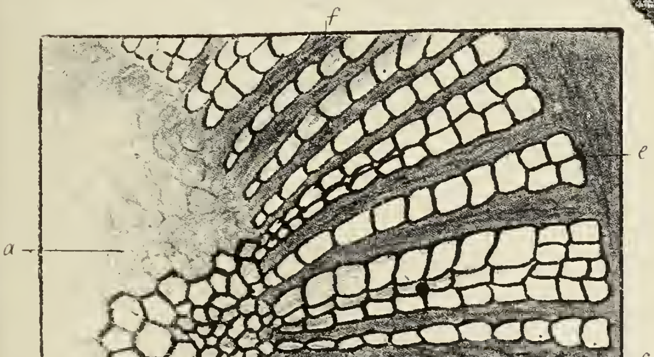


Fig. 4 *

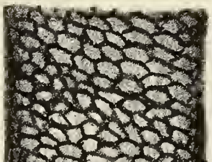
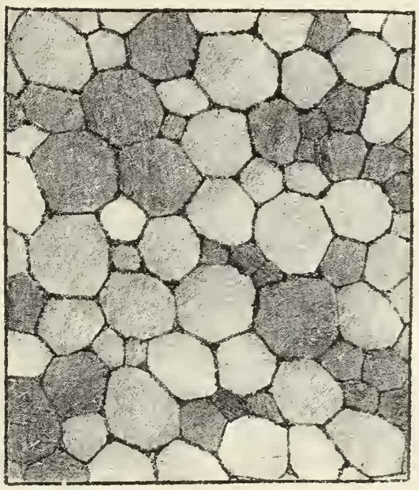


Fig. 5.



LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Fig 6.

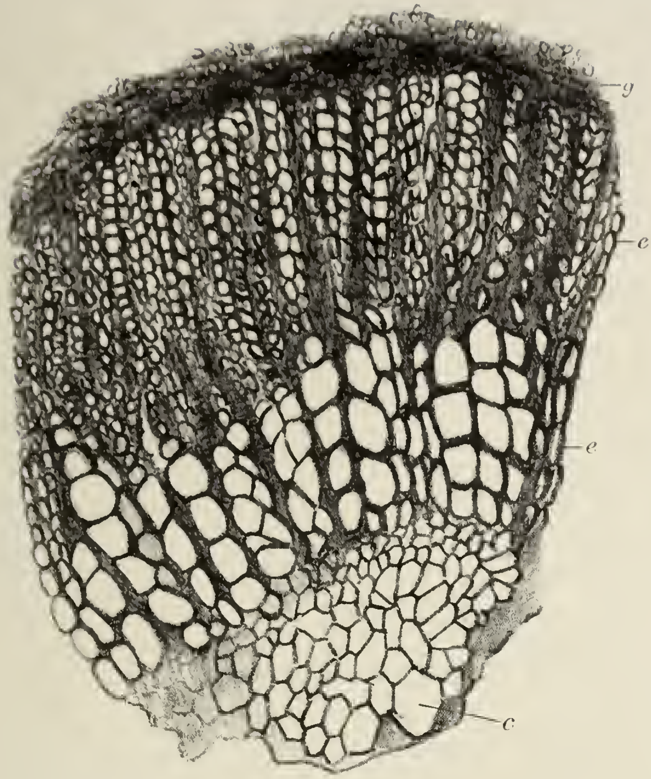


Fig 7

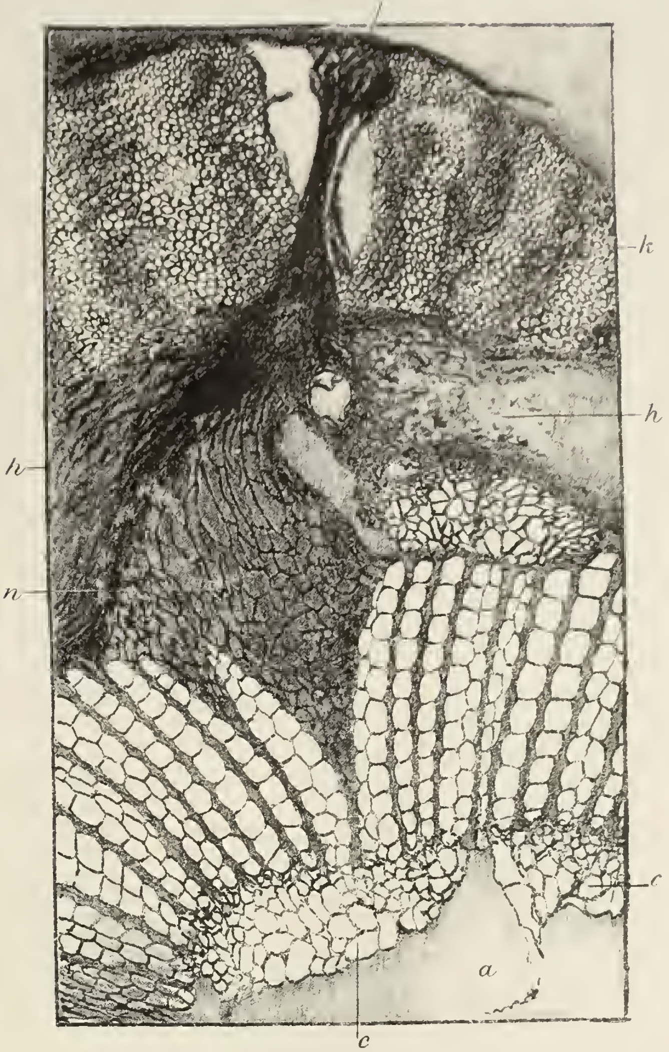


Fig 8.

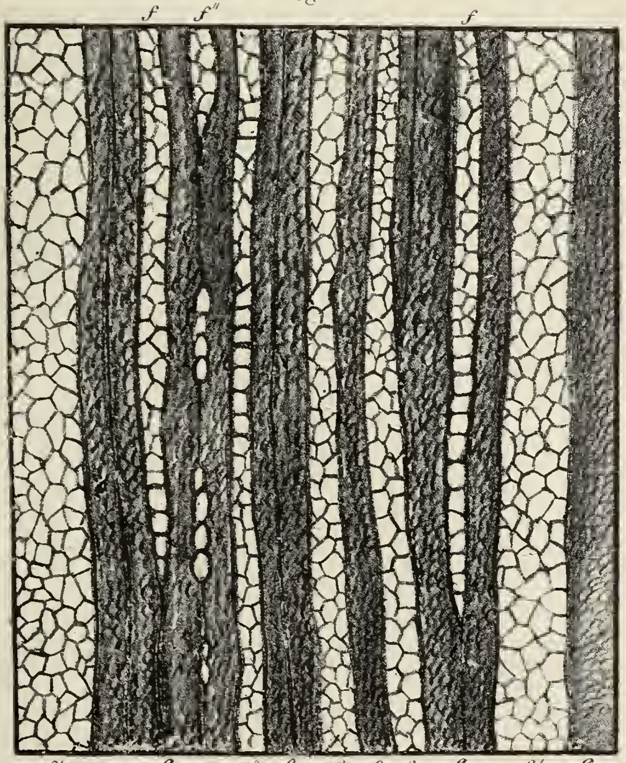
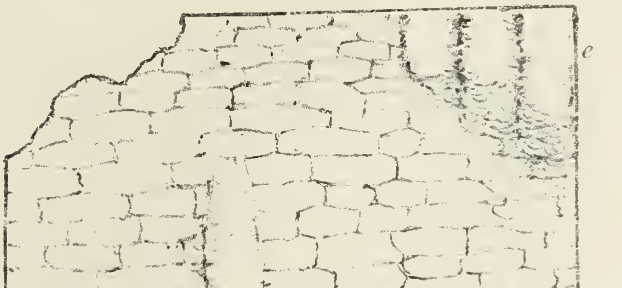


Fig. 9.



LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Fig. 10.

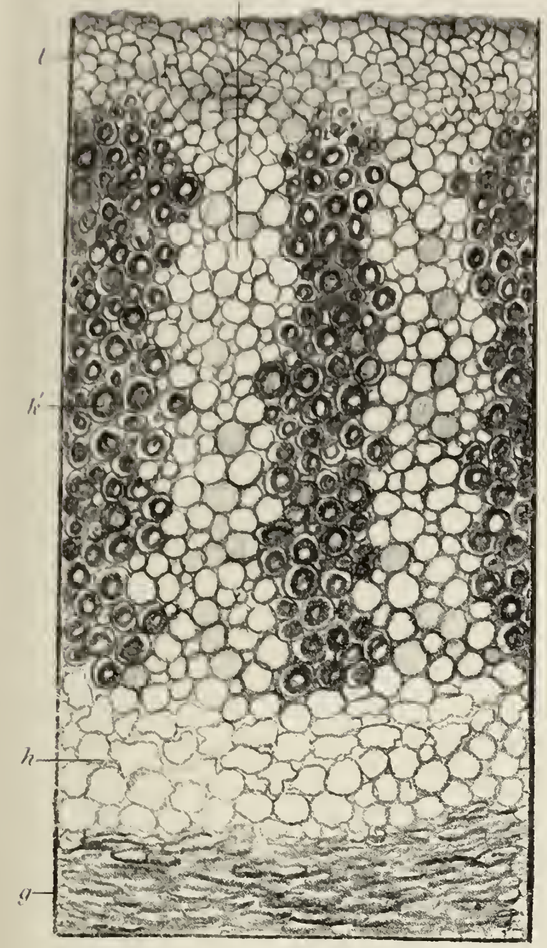


Fig. 11.

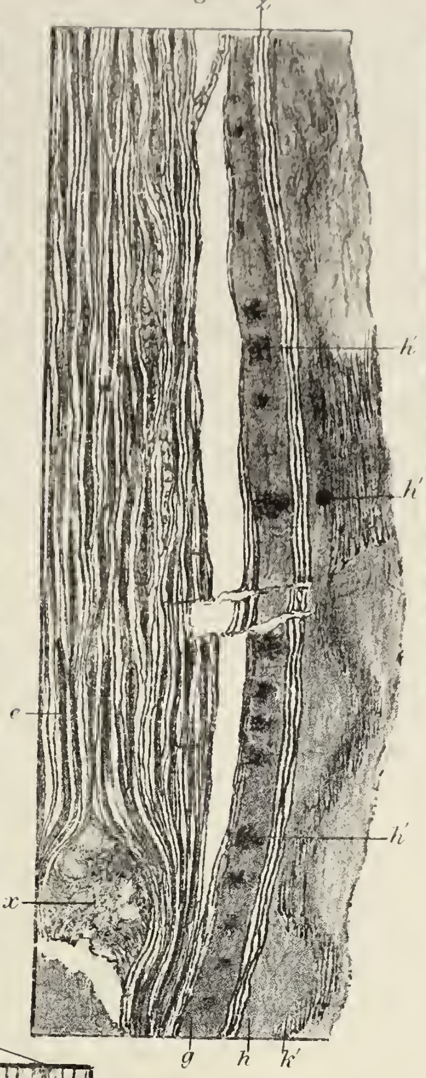


Fig. 15.

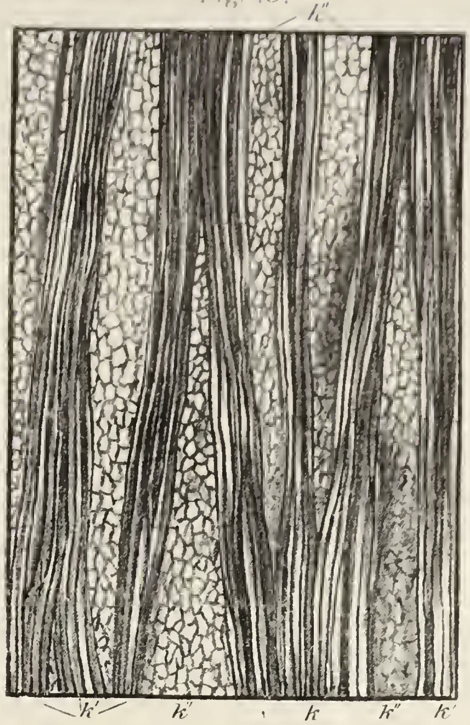


Fig. 12.

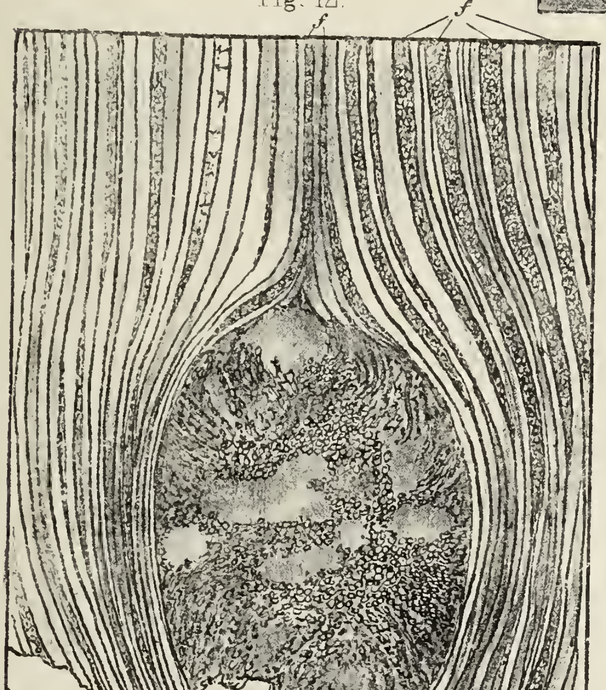
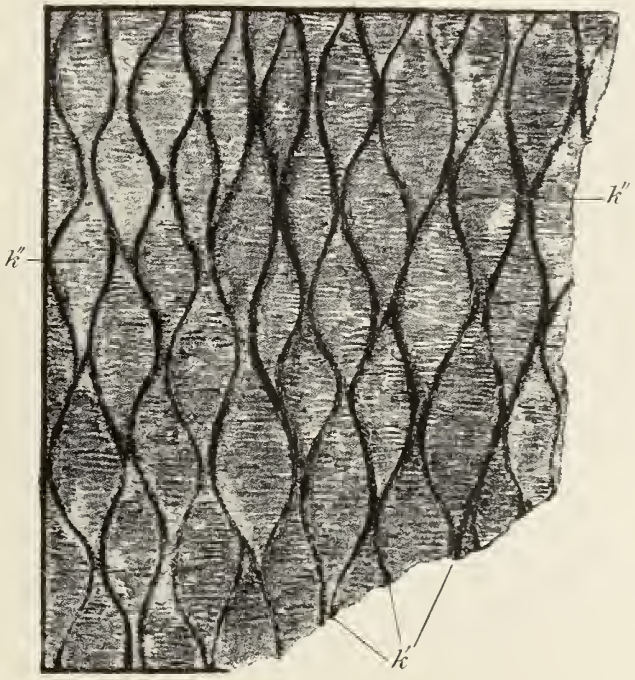


Fig. 13.



W. C. Williamson, Auto-Lith.

Maclure & Macdonald, Lith. London

LIBR
OF T
UNIVERSITY OF ILLINOIS

Fig. 14.

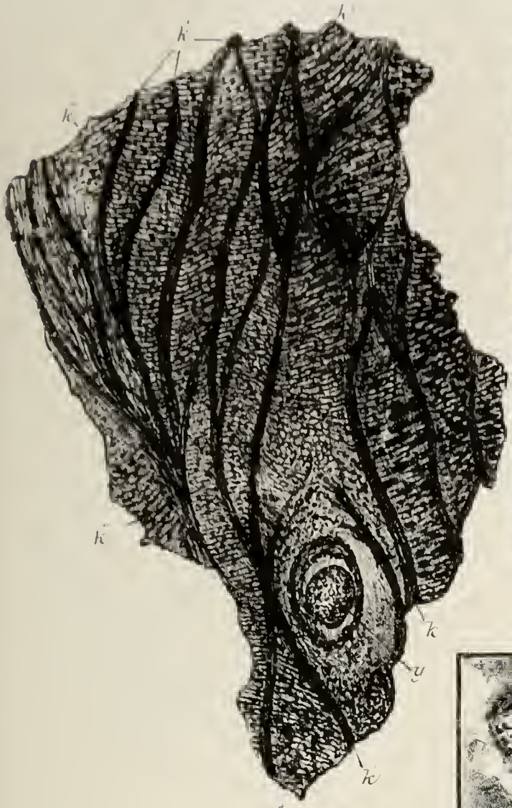


Fig. 16.

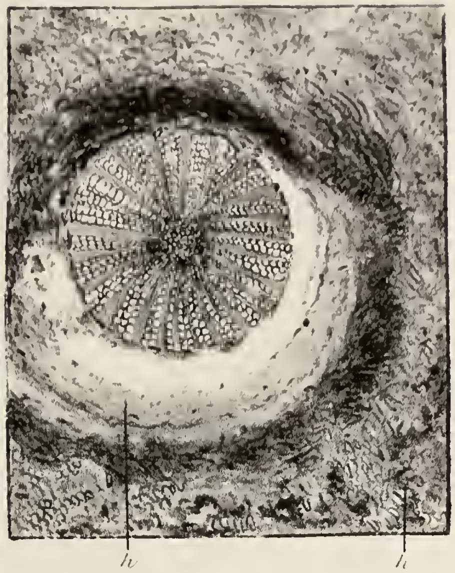


Fig. 17.

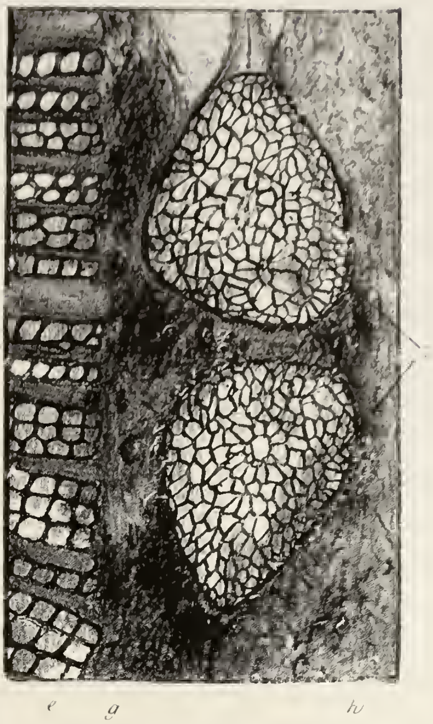


Fig. 21.

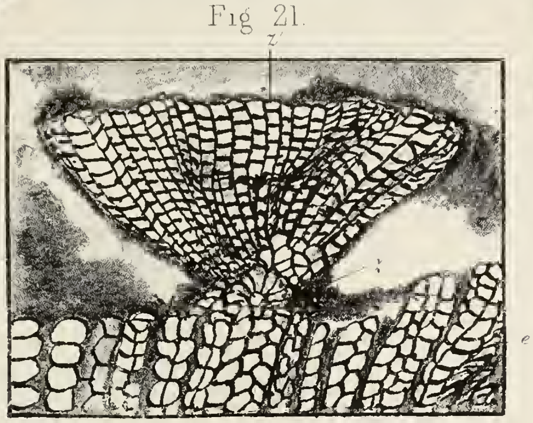


Fig. 19.

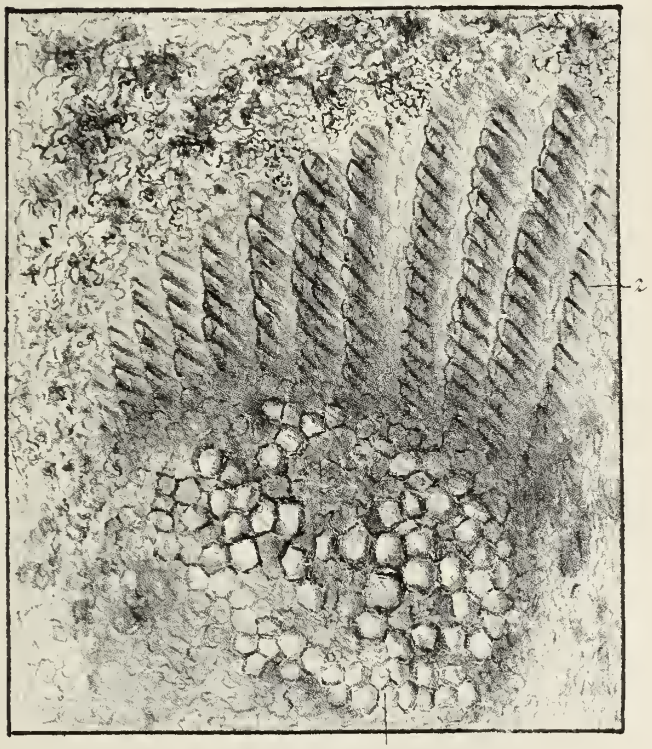
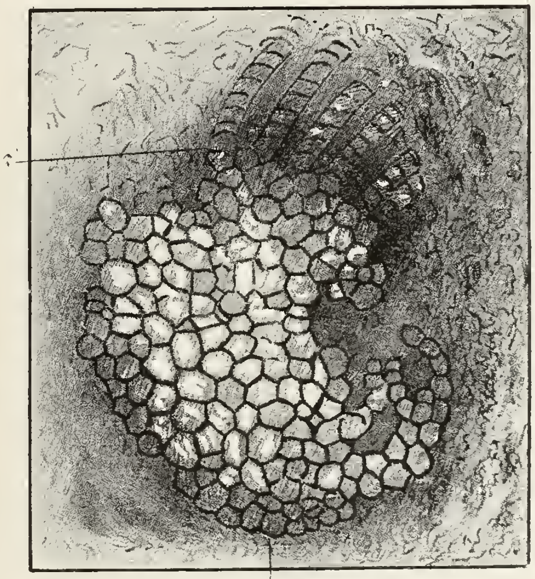


Fig. 20.



W. C. Williamson, Auto Lith.

Mintern & Macdonald, Lith. London.

LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Fig. 18.

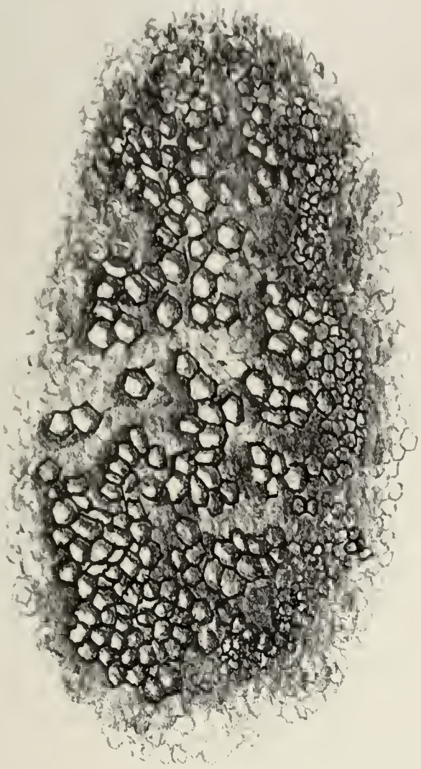


Fig. 22.

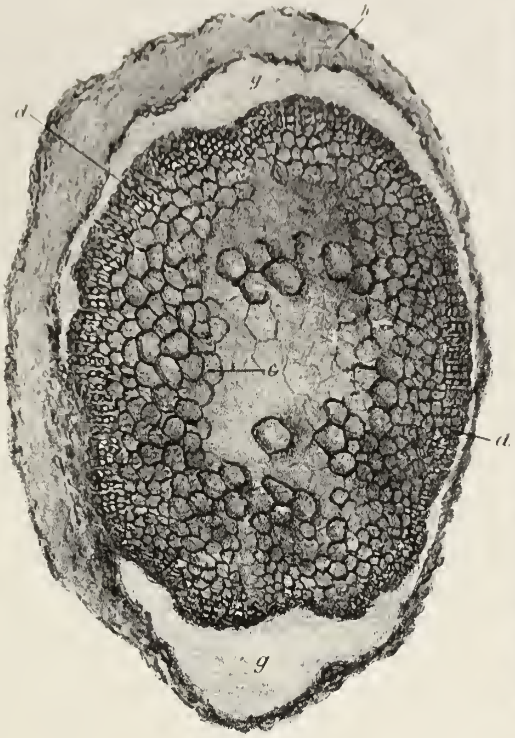


Fig. 24.

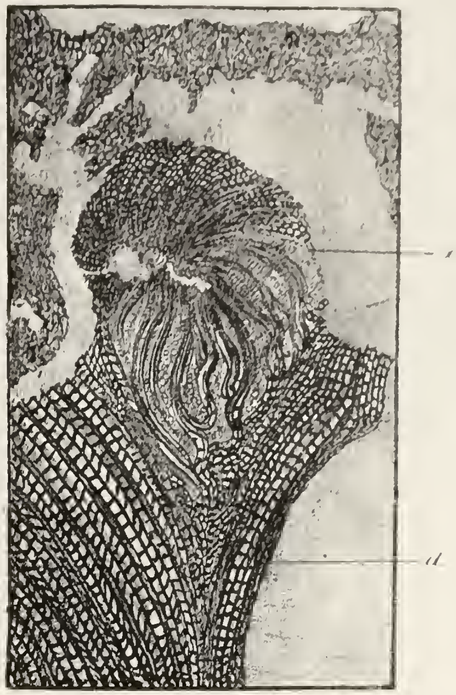


Fig. 23.

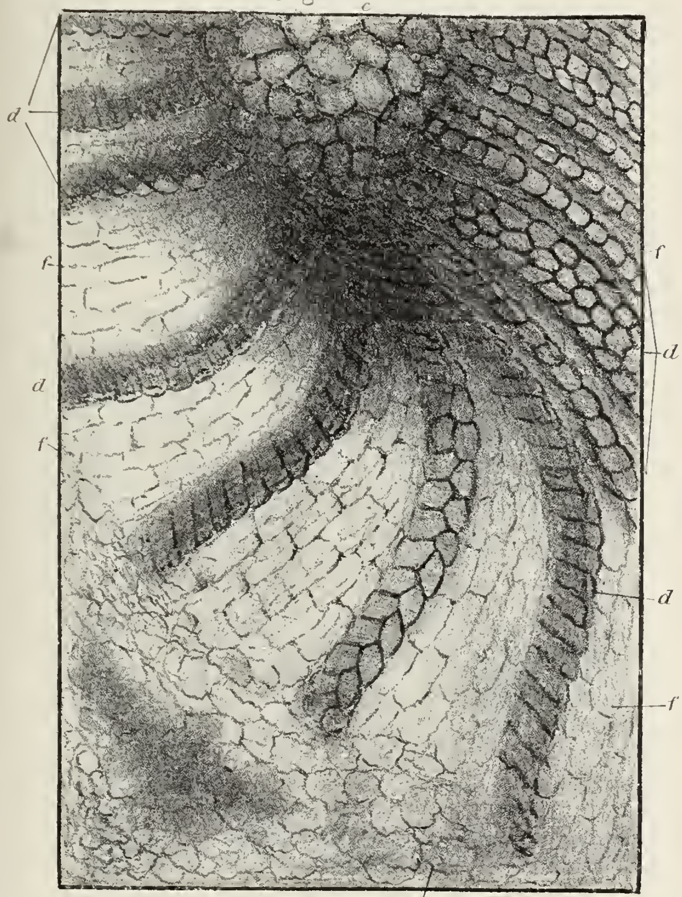
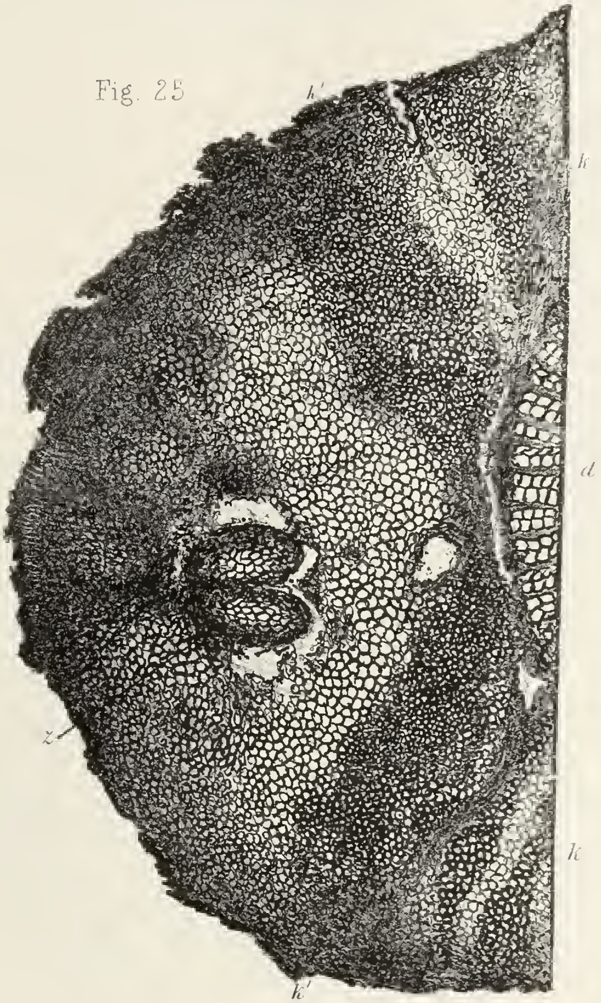
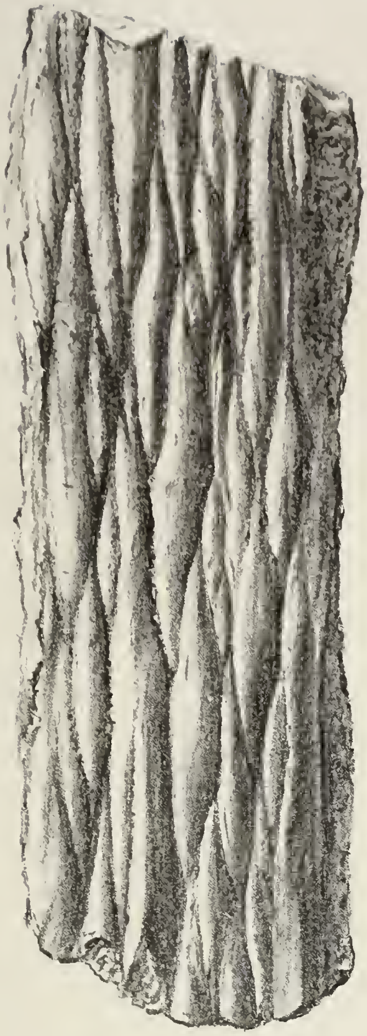


Fig. 25



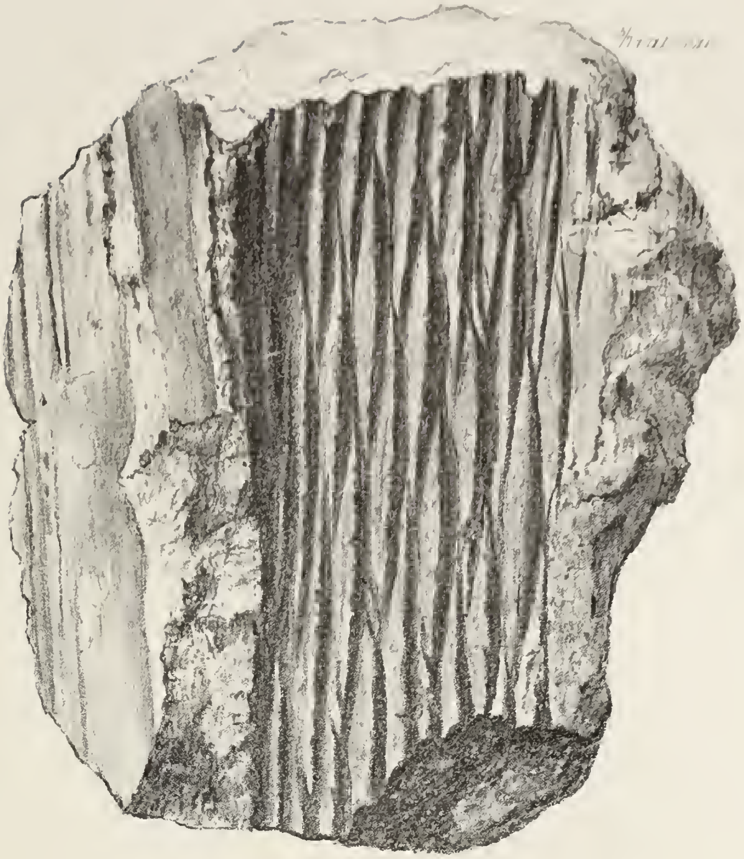
LIBR
OF T
UNIVERSITY o ILLINOI

Fig. 26



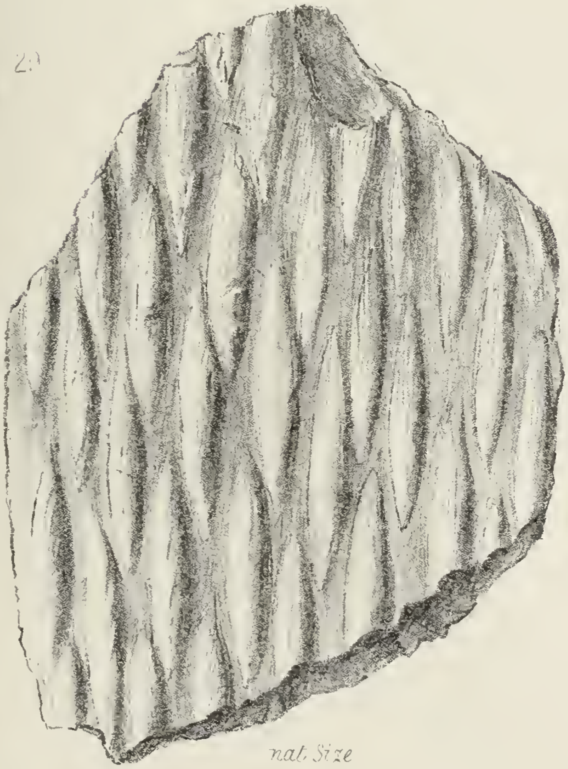
nat. Size

Fig. 27



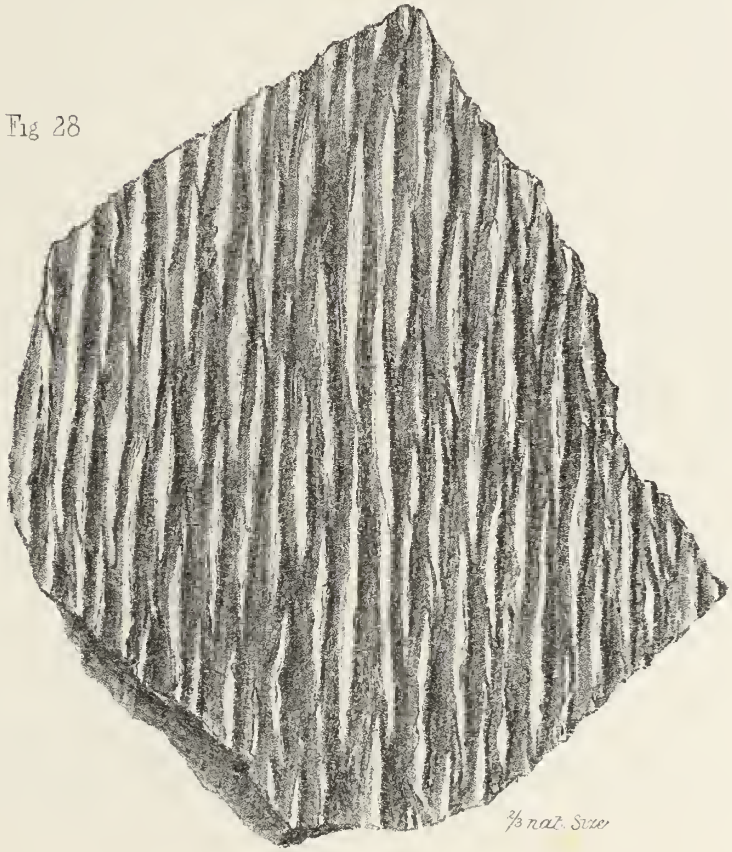
⅔ nat. size

Fig. 29



nat. Size

Fig. 28



⅔ nat. Size

LIBR
OF THE
UNIVERSITY of ILLINOI

Fig. 46

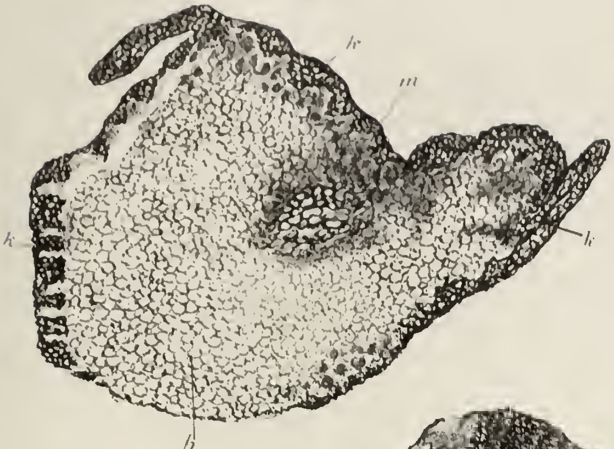


Fig. 31

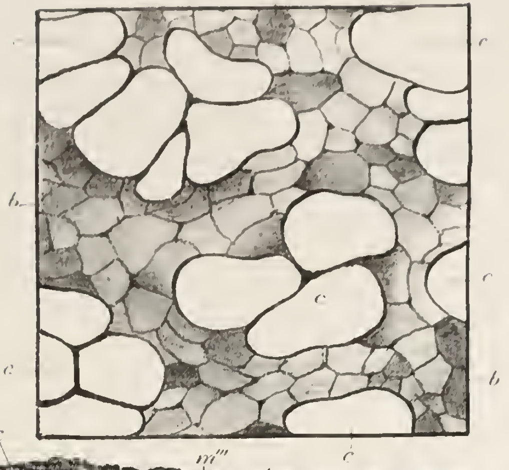


Fig. 30

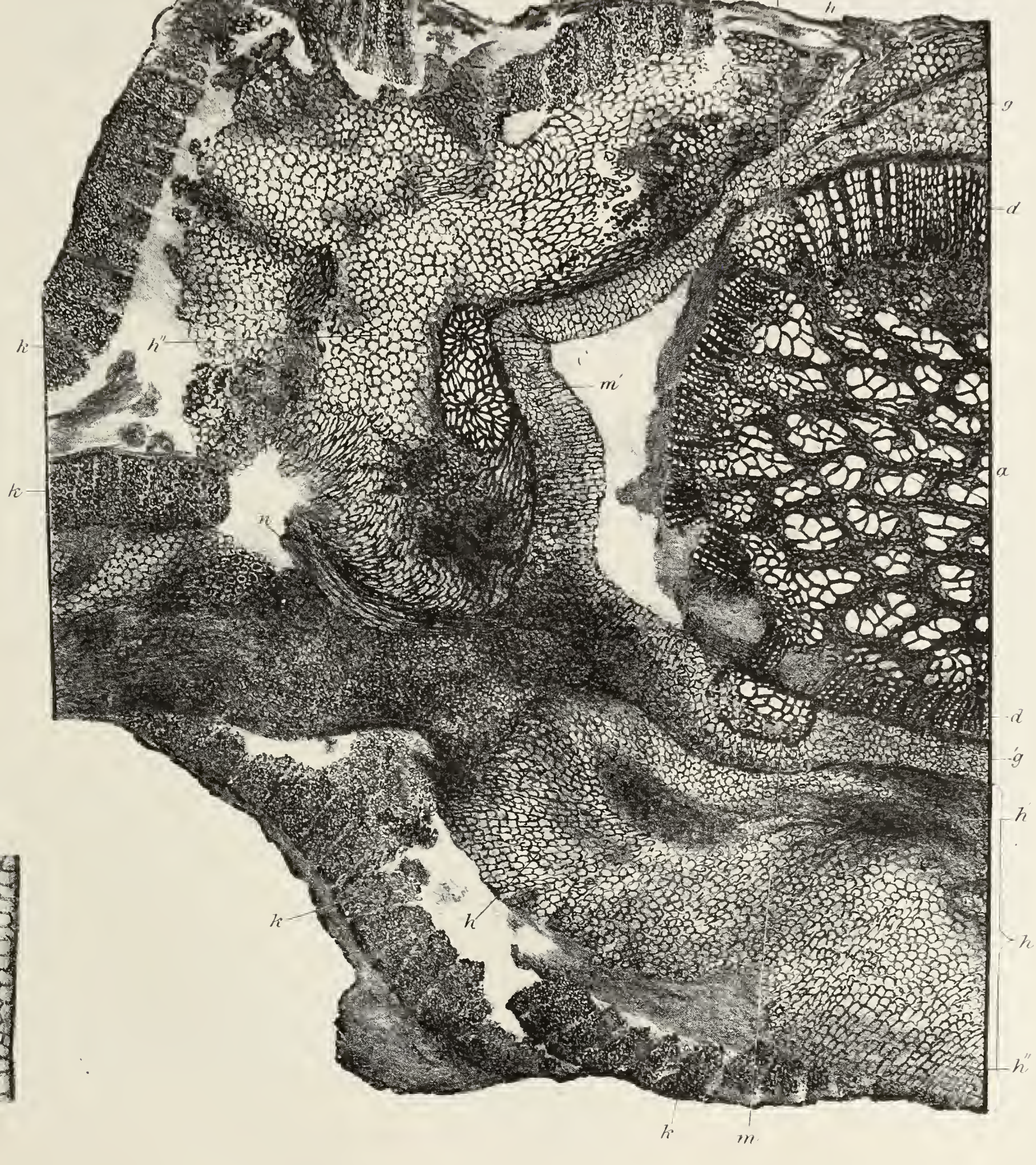
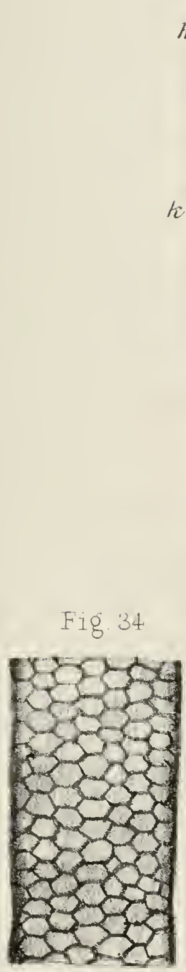


Fig. 34



UNIVERSITY OF ILLINOIS

Fig. 34.

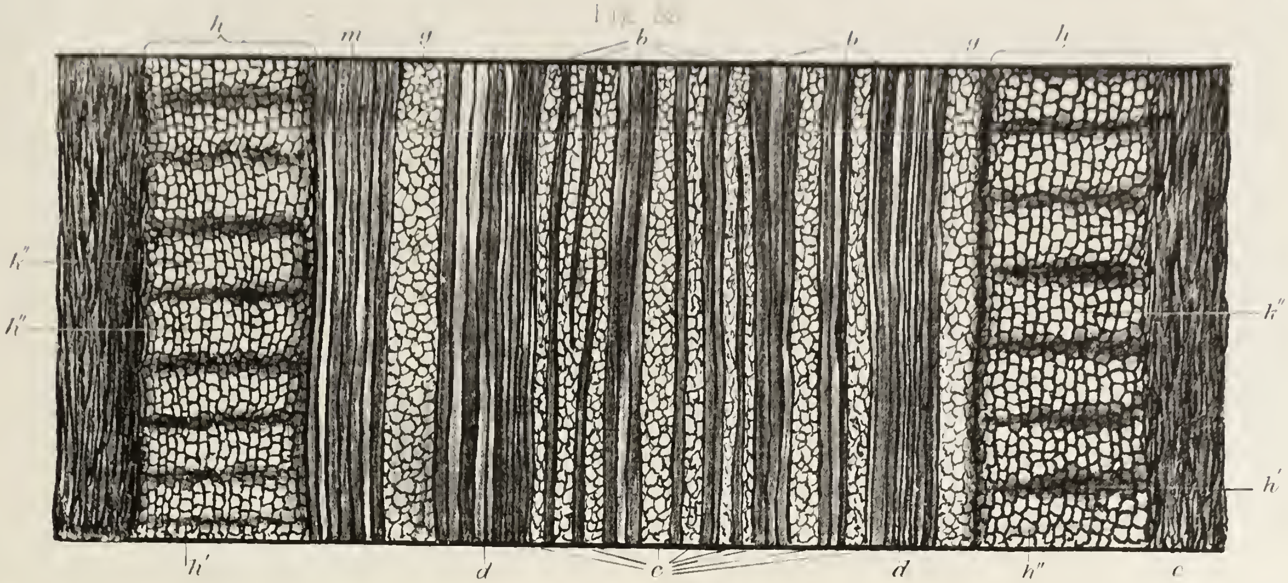


Fig. 33.

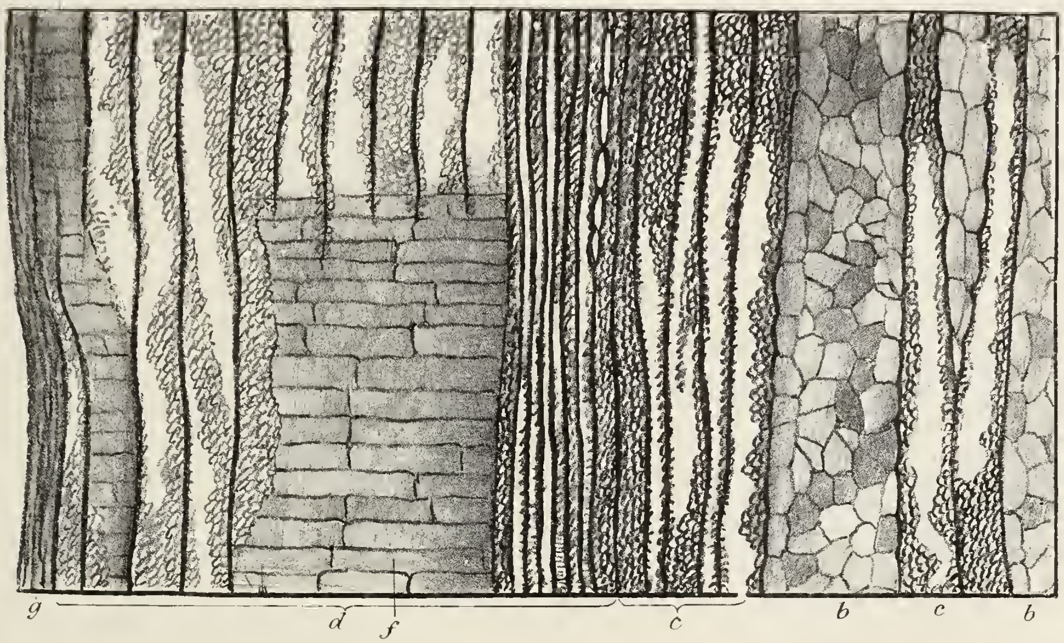


Fig. 33a.

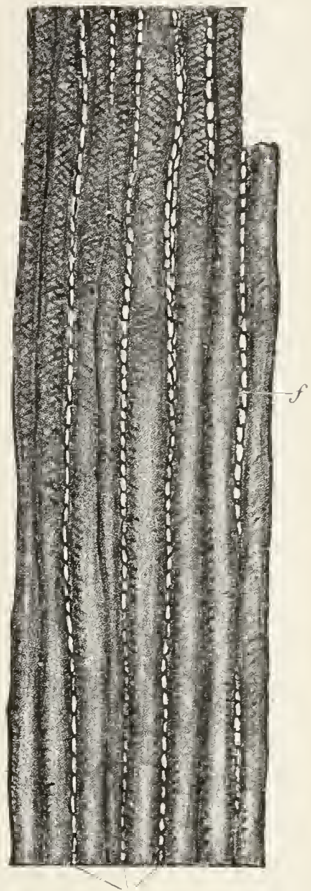
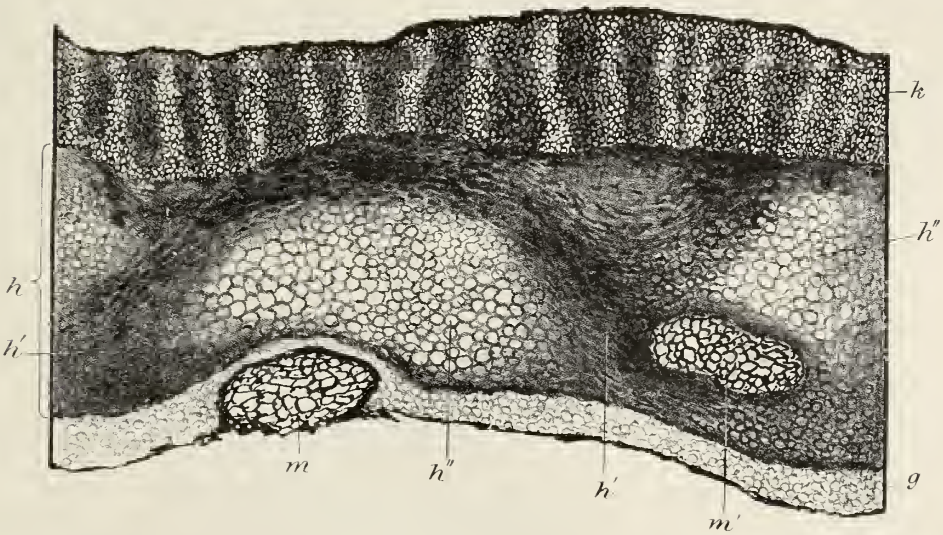


Fig. 35.



LIBRARY
OF THE
UNIVERSITY of ILLINOIS

Fig. 37.

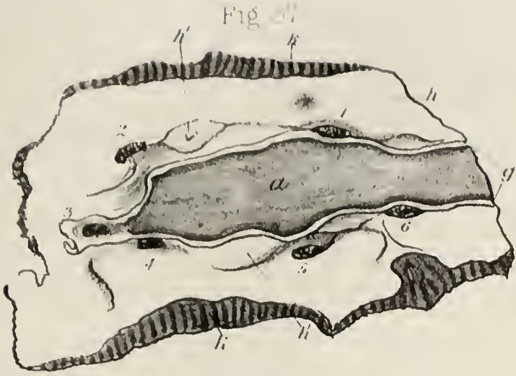


Fig. 41.

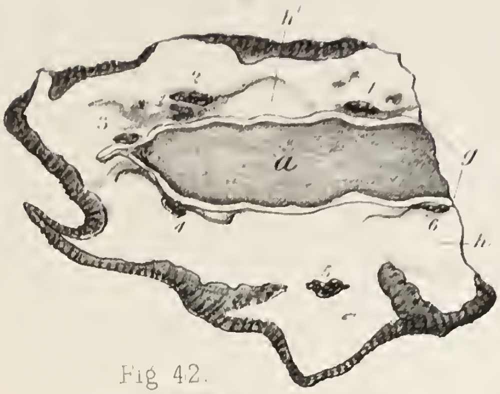


Fig. 38.

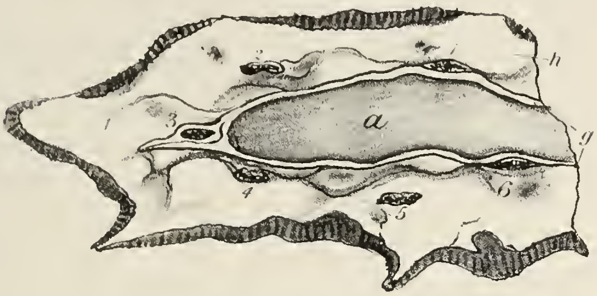


Fig. 42.

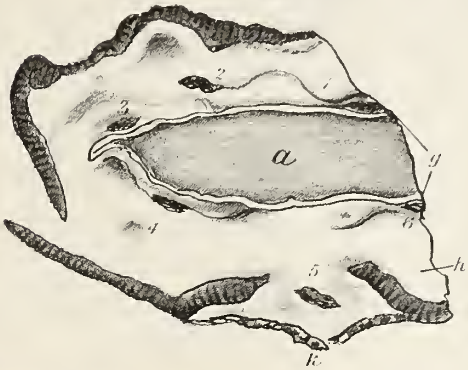


Fig. 36.

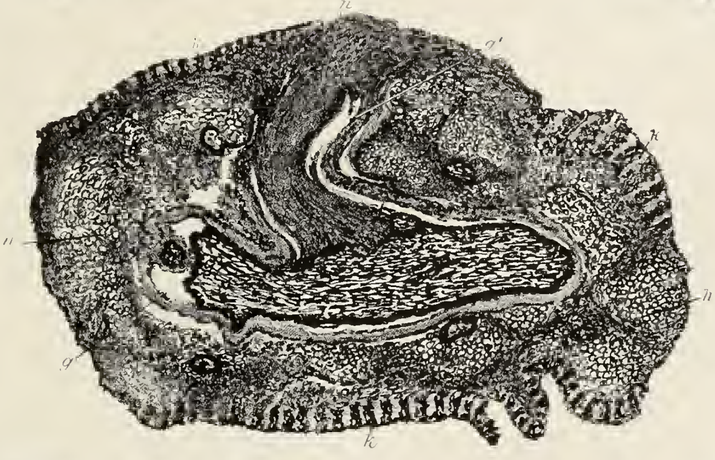


Fig. 39.

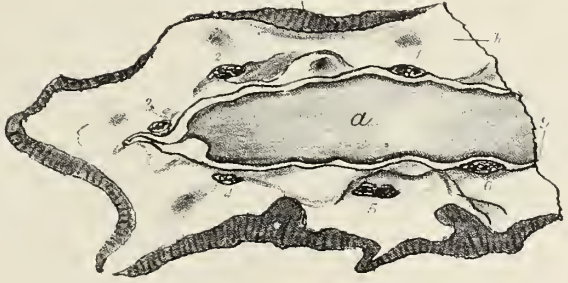


Fig. 43.

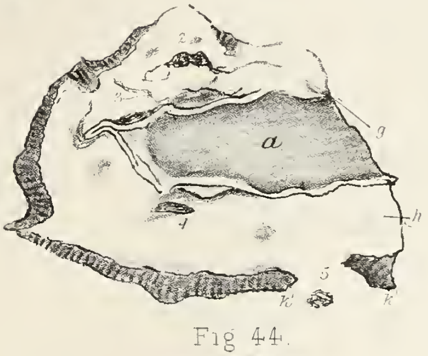


Fig. 40.

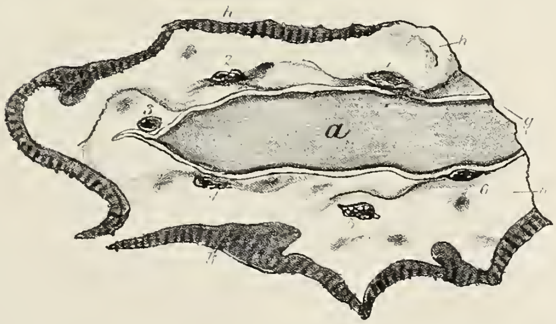
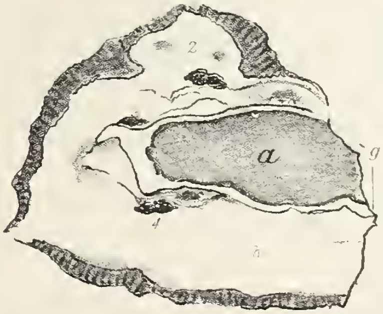


Fig. 44.



LIBRARY
OF THE
UNIVERSITY of ILLINOIS

Fig 48

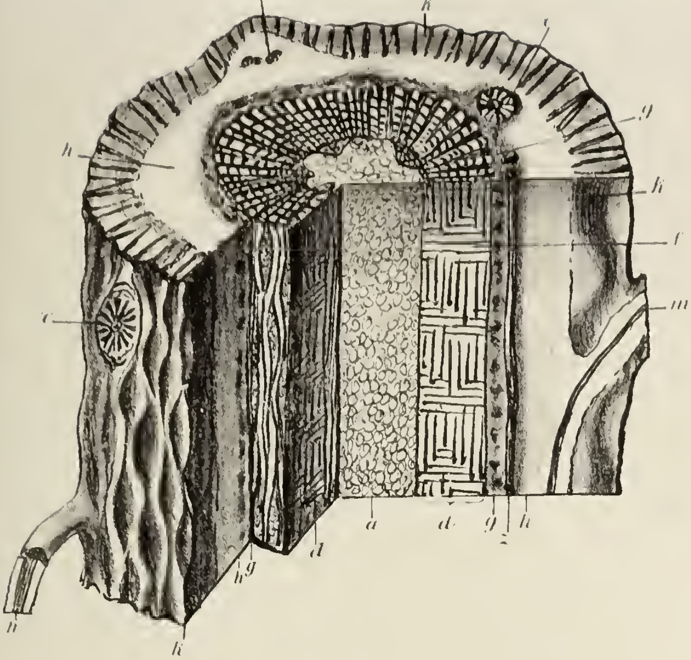


Fig 47

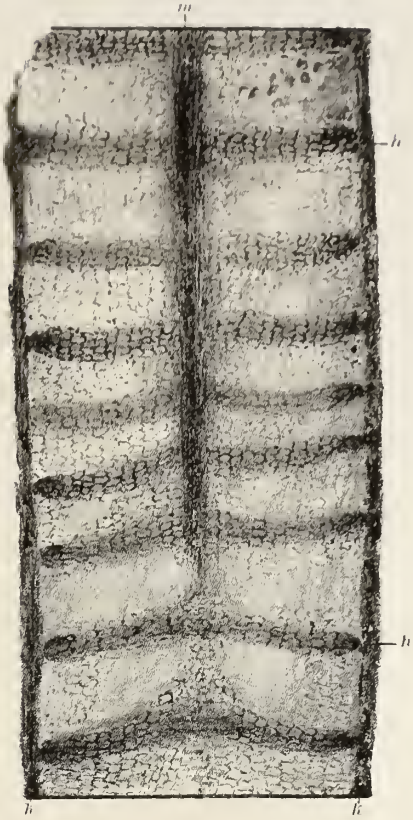


Fig 49.

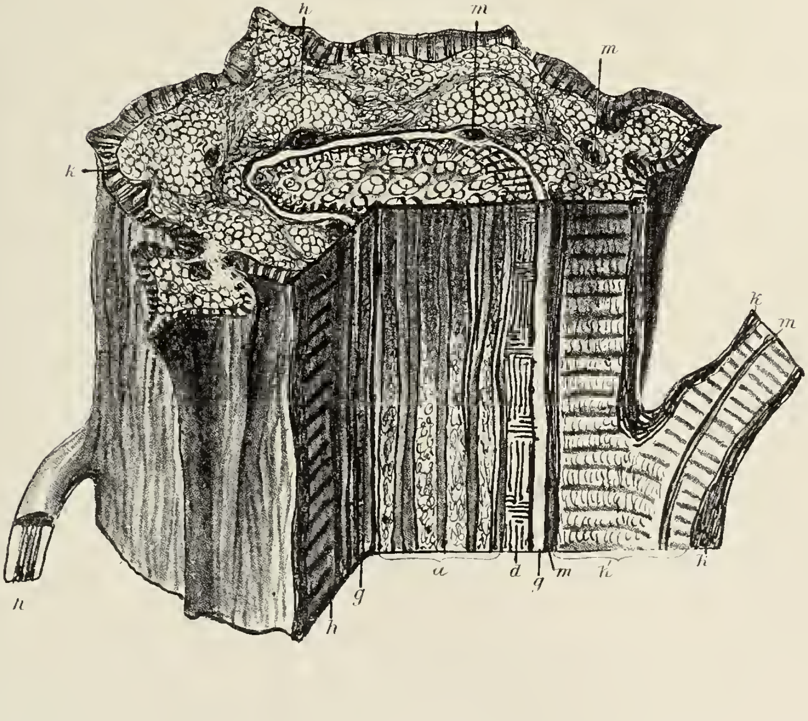
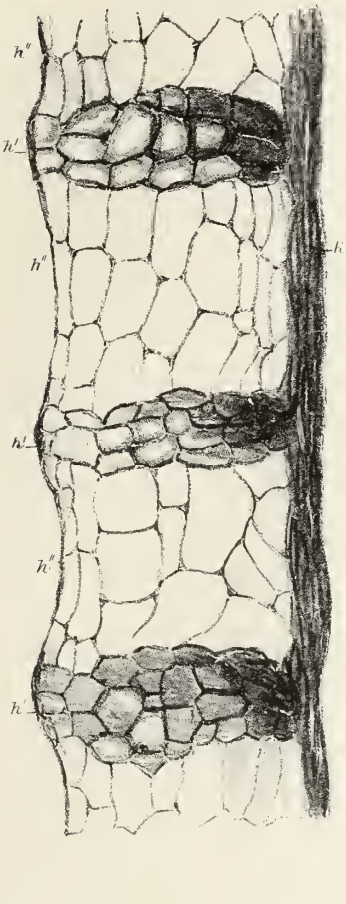


Fig 45



LIBRARY
OF THE
UNIVERSITY of ILLINOIS

XI. *Determination of the Number of Electrostatic Units in the Electromagnetic Unit made in the Physical Laboratory of Glasgow University. By* DUGALD M'KICHAN, *M.A. Communicated by Sir* WILLIAM THOMSON, *F.R.S. &c.*

Received April 15,—Read May 15, 1873.

THE object of the following paper is to describe observations made to determine the relation between the fundamental units in the electromagnetic and electrostatic systems of absolute measurement.

These observations were made at intervals from 1870 to 1872, first in the Physical Laboratory of the Old College, Glasgow, and afterwards in that of the New College.

In the former series of experiments I had the advantage of the assistance of the late WILLIAM LEITCH, of Glasgow[*]. The latter series I made chiefly with the assistance of GEORGE A. HILL, M.A., now Assistant Professor of Natural Philosophy in Harvard College, U. S.

A summary is also given of the results of similar experiments made by Mr. WILLIAM F. KING in the Old College in 1867 and 1868.

The two systems of absolute electrical measurement are founded on the fundamental units of time, mass, and space applied to the observed effects of electricity at rest and electricity in motion, the one system having a definite numerical relation to the other. The number of electrostatic units in the electromagnetic unit of quantity, from the dimensions of the unit of quantity in the two systems, is expressible as a velocity, and is usually designated by the symbol v.

In the Report of the British Association's Committee on Electrical Measurements, 1863, five possible methods are enumerated for experimentally determining v. It is necessary and sufficient that we should obtain a common electromagnetic and electrostatic measure of some electric quantity, current, resistance, electromotive force, or capacity.

The first numerical determination of v had been made by WEBER and KOHLRAUSCH[†], who had employed the method last indicated: they derived the value of v from a common measure of capacity. The capacity of a condenser was measured electrostatically by comparison with the capacity of a sphere of known radius, and electromagnetically by passing the discharge from the condenser through a galvanometer. The value of v derived from their experiments was $310{\cdot}74\times10^8$ centimetres per second.

---

[*] Mr. LEITCH afterwards went out to introduce Sir WILLIAM THOMSON's Siphon-recorder at the various stations of the Eastern Telegraphs. He died on his way home, at Alexandria, after he had completed his work.

[†] POGG. Ann., Aug. 1856, Band xcix. p. 10.

Professor CLERK MAXWELL has pointed out[*] a probable source of error in these experiments of MM. WEBER and KOHLRAUSCH. A neglect, in the measurement of the capacity of the condenser, of the phenomenon of "electric absorption," the nature of which was not then well understood, would lead to an overestimation of the electrostatic capacity of the condenser, and consequently to a value of v which would be too great.

In the same paper Professor CLERK MAXWELL describes a direct comparison of electrostatic with electromagnetic force in which no absolute measurement of either was made. The ratio of electrostatic and electromagnetic units of quantity was determined by a direct experiment, in terms of the British-Association Unit of Resistance, by a balance of the electrostatic attraction of two disks maintained at a great difference of potentials and the electromagnetic repulsion of two circular coils attached to the attracting disks. The mean value of v derived from this comparison was $288 \cdot 0 \times 10^8$ centims. per second.

In the experiments to be described, the method employed was that of obtaining a common measure of electromotive force. The electromotive force produced by a battery can be measured directly in absolute electrostatic units; its electromotive force can also be obtained in electromagnetic measure from the current which it produces in a circuit of known resistance.

The measure of electromotive force from one point to another being defined (in the two systems) as the work done by electrical forces during the passage of unit quantity of electricity from the one to the other, v, the ratio of the units of quantity in the two systems, is also the inverse ratio of the units of electromotive force.

For this comparison three independent measurements are required—the determination of the resistance of the given circuit in absolute measure, the electrostatic measure of electromotive force produced by a given battery, and the electromagnetic measure of the current maintained in the circuit by this electromotive force.

The resistance of the circuit was obtained, according to the usual method, from a comparison with resistance-coils derived from standards the resistance of which had been experimentally determined in absolute measure by observations completed in 1864 at King's College, for the Committee of the British Association, by Professors J. CLERK MAXWELL, BALFOUR STEWART, and FLEEMING JENKIN. Accordingly, whatever corrections may hereafter be discovered to be applicable to the absolute value of the unit of resistance must be applied to the value of v here determined. It is hoped that Professor MAXWELL will soon be able to accomplish the new determination of the absolute resistance of the standard coil which he proposes to make in the Cavendish Laboratory, Cambridge University.

The electromotive force of the battery, which consisted of a series of DANIELL'S cells, was measured electrostatically or weighed by means of Sir WILLIAM THOMSON'S New Absolute Electrometer. A description of this instrument will be found in a "Reprint of Papers on Electrostatics and Magnetism" by Sir WILLIAM THOMSON, §§ 364–367.

---

[*] Philosophical Transactions, 1868, p. 651.

The New Absolute Electrometer is identical in principle with the Absolute Electrometer described in the Report of the British Association, 1867. The principal improvements in the new instrument are the introduction of a new sighting arrangement, by which errors from parallax are avoided, the substitution of a metal disk supported by springs for the disk balanced by a counterpoise, and the addition of an idiostatic gauge and a replenisher, by means of which the charged disk can be maintained at a constant potential. By this instrument the force of attraction between two disks of known area at a constant difference of potentials is measured in grammes weight. The difference of potentials between the two poles of a battery can thus be measured, and the area, force, and distance being known, can be expressed in absolute electrostatic units of space, time, and mass. In these measurements the units employed were:—for unit of mass the gramme, for unit of time the second, and for unit of space the centimetre.

The strength of the current was measured by the force acting between two portions of itself in the circuit of an electrodynamometer (see Plate XXXII. figs. 1 & 2). This circuit consisted of three coils, two large fixed coils (a, b), and a third smaller coil (c) movable round a vertical axis. The larger coils contained each upwards of 3700 metres of fine silk-covered wire wound upon brass rings, 30 centims. in diameter, with parallel flanges about $2\frac{1}{2}$ centims. broad.

The two coils contained on an average 3700 turns of wire each, the depth of the coils being somewhat less than 2 centims. and the breadth of the rings being 2 centims. One end of the wire in each, before winding, was soldered to the ring, the ring thus forming one of the terminals of the coil. The two coils were placed on an oblong wooden pedestal (h) (supported on three screws) with their planes vertical and parallel to one another, the line joining their centres being perpendicular to the plane of each coil. The rings were fitted to wooden concave supports (g, g'), to which they were secured by two bars of wood (f, f') resting across the rings on the inside, and firmly attached by means of screws to the wooden stand. The parallelism of the coils was preserved, as far as possible, by means of stout hard-wood bars of equal length (i) inserted at intervals between the rings perpendicular to the planes of the coils. To secure the most uniform magnetic field in the neighbourhood of the coils, the HELMHOLTZ arrangement of the coils was chosen, the distance from centre to centre of the coils being approximately equal to their radius.

The movable or suspended coil (c) consisted of upwards of 900 metres of finer wire. The brass ring upon which it was wound was $6\frac{1}{2}$ centims. in diameter, and had flanges $2\frac{1}{2}$ centims. broad. It contained upwards of 3000 turns of wire, the depth of the coil being 2 centims. and its thickness $1\frac{1}{2}$ centim.

This movable coil, which was suspended between the two fixed coils, was protected from disturbing currents of air by a wooden box (k) which stood between the two fixed coils, being fastened to the stand on which they rested. On one side perpendicular to the planes of the coils this box was left open; and after the coil had been suspended, a glass screen was introduced. Subsequently, to prevent any error from distortion of the rays of light passing through the glass, and to avoid any unnecessary diminution of their brightness, the glass was removed and sheets of cardboard, with apertures through which the rays might pass, were substituted. Two or three such screens (*l*), their apertures varying in size with the distance of each screen from the coil, formed a sufficient protection to the coil from currents of air. The box was large enough to admit of the free motion of the coil through a considerable angle; and for temporary adjustments the coil was accessible from behind, an aperture being left which was closed while observations were being made, but which could be opened when necessary.

The coil was not suspended from the roof of the box, which did not stand so high as the outside coils; but a higher point of suspension was found by erecting a brass vertical tube (*d*), about 2 centims. in diameter and 35 centims. in length, over an aperture in the roof of the box. The suspending-wire was attached to the cover (*e*) which closed this tube. This cover or lid, which fitted into the mouth of the tube, being movable, the position of the coil in azimuth was easily adjustable. The suspending-wire, which acted also as a conducting-wire, was soldered to a cross piece fixed to the flanges of the ring at right angles to them: this wire, being thus in metallic connexion with the ring to which one end of the insulated wire was soldered as in the fixed coils, served as one of the terminals of the suspended coil. The other end of the insulated wire was soldered to a brass terminal set in a cross piece of vulcanite at the bottom of the coil: to this terminal a long very fine platinum wire was attached, its other end being soldered to a stout wire fastened to the bottom of the box, and leading out to the other connexions.

The movable coil was suspended symmetrically with respect to the fixed coils. Its centre was accurately marked on a piece of wood temporarily inserted inside the ring. The coil was then raised by means of the suspending-wire until this centre coincided with a fine wire temporarily fixed in the line joining the centres of the fixed coils.

Again, by altering the position of the vertical tube relatively to the box to which it was fastened, the fixed coils being kept vertical, the vertical axis of the coil was adjusted to be equidistant from the planes of the fixed coils.

The three coils just described were joined in series, the connexions being so arranged that a current passing through the three coils should pass in the same direction through the two fixed coils so that they should conspire in their action on the movable coil.

The strength of the current was measured by the deflection of the suspended coil. In order that this determination, by means of the deflection, might be absolute, it was necessary to eliminate the effect due to the horizontal component of the earth's magnetism. This was done by observing the deflections when a given current passed first in the one direction and then in the other, the relations between the coils themselves remaining fixed. The mean deflection was that due to the simple action of the coils. To render the discrepance between the two deflections as small as possible, magnets were fixed in the neighbourhood of the coils to neutralize the action of terrestrial magnetism, and the deflections due to equal and opposite currents were as nearly as possible equalized.

If it had been possible to adjust the magnets so as exactly to counterbalance the directive component of the earth's magnetism, these deflections would have been exactly equal; but a slight discrepance between the deflections remained after the adjustment of the magnets. This remaining discrepance was eliminated in the calculation by taking the mean between the two deflections.

These deflections, which were measured according to the usual method by reflection, were read off on a scale (Plate XXXII. fig. 3, *f*) (divided to fortieths of an inch) placed at a distance of 3 or 4 metres from the coil. The light (from a gas-lamp constructed like a paraffin-lamp with glass shade &c. supported on a wooden frame attached to the table on which the electrodynamometer stood) was reflected from a light circular mirror (*m*) cemented to the lower part of the front of the movable coil. The lamp (*a*) was placed about midway between the electrodynamometer and the scale, the reflected rays passing under it from the mirror away to the scale. The rays reached the mirror after passing through a condensing-lens (*c*) attached to a long telescope-tube (*b*), the position of which, relatively to the lamp and mirror, was adjusted by moving the tripod stand (*d*) to which its supports were attached. The lamp carried a metal screen with slit and fine wire stretched across the slit; and the deflections were noted, as in reflecting galvanometers and electrometers, from the positions of the shadow of this wire in the reflected image.

To render these deflections available for absolute measurement, it was necessary to know in mechanical units the force required to maintain the coil deflected through any given angle. This force is given by the equation of oscillations in terms of the period of vibration and the moment of inertia of the coil round its vertical axis. The period of vibration of the coil was determined from a series of 110 periods. The times of the first 10 and the last 10 having been noted, and the differences of the times of the 1st and the 101st, the 2nd and the 102nd, &c. having been taken, the average period of vibration for the whole series was very accurately determined. As the deflections to be observed in the actual measurements were made in a magnetic field with the coil deflected from its zero-position, these observations of the period were repeated with the coil deflected under the influence of the current about to be used in the comparison. A result differing by nearly $\frac{1}{2}$ per cent. was sometimes obtained. This determination of the period of vibration of the coil was generally repeated before any lengthened series of observations.

The moment of inertia of the coil round its vertical axis was obtained from a comparison of its vibrations with those of a symmetrical body of the same weight vibrating under the same conditions. The coil having been carefully weighed, a vibrator of the same weight was constructed. The vibrator consisted of a cylindrical brass ring (radius 5 centims.) and a light brass bar attached at its extremities to the ring. This was made to vibrate, in an enclosed space protected from currents of air, round an axis perpendicular to the plane of the ring, the suspending-wire being attached to the centre of the cross bar. The image of a light reflected from a galvanometer-mirror fixed to the vibrator at its axis allowed these vibrations to be easily counted. The period of vibration was determined from a series of oscillations extending through 110 periods. The vibrator having been removed from the suspending-wire, the coil was substituted in its place (care having been taken that the wire was not subjected to any stretching in the interval); and a similar series of observations was made to determine the period of vibration of the coil. The moments of inertia of any two bodies of equal weight around any axis being proportional to the squares of their periods of vibration round these axes, the ratio between the moment of inertia of the suspended coil and the moment of inertia of the ring-vibrator was given by this comparison.

The dimensions of the vibrator were accurately known, and the summation was made for all its parts. This, together with the ratio just obtained, gave the moment of inertia of the movable coil round a vertical axis through its centre in centimetre-grammes. This moment of inertia, combined with the period of vibration of the coil after it was suspended in the electrodynamometer, gave the absolute measure of the couple required to hold the coil deflected through unit-angle or any fraction of unit-angle. The length of a scale-division and the distance of the scale from the mirror being known, the angular value of a deflection through any number of scale-divisions was known, and consequently the deflecting couple corresponding to each reading on the electrodynamometer scale.

The electromagnetic measure of this couple was obtained in terms of the strength of the deflecting current from a consideration of the number of turns of wire in the coils and the area they enclosed, the distance of the movable coil from the fixed coils, and other quantities entering into the equation below. These two values, the mechanical and the electromagnetic (which for any given deflection must be equal to one another), having been equated, the strength of the current was obtained in mechanical or absolute electromagnetic units, the unit strength of current being defined, in a purely mechanical way, as "that current of which the unit of length placed along the circumference of a circle of unit radius produces a unit of magnetic force at the centre."

The methods of obtaining the corresponding absolute measurement of the resistance of the circuit and the electrostatic measure of the electromotive force have been already mentioned. These three measurements afford the data from which the ratio v is to be obtained.

Mathematical Theory of the Comparison.

I. Absolute Electrometer (see "Reprint" above referred to, § 362).

Let F=force (determined by experiment) required to displace the movable disk of the electrometer through a known distance.

A=mean of the areas of the disk and the aperture of the guard-ring which surrounds it.

V=difference of potentials between the disk and the opposed plate connected with one of the poles of the battery.

V′=difference of potentials between the disk and the opposed plate connected with the other pole of the battery.

D=distance through which the opposed plate has to be moved from its zero position to bring the disk again into the sighted position after one of the poles of the battery has been connected with the opposed plate.

D′=distance through which the opposed plate has to be moved from its zero position to bring the disk again into the sighted position after the other pole of the battery has been connected with the opposed plate.

Then $V=D\sqrt{\frac{8\pi F}{A}}$,

$$V'=D'\sqrt{\frac{8\pi F}{A}},$$

$$\frac{V-V'}{2}=\frac{D-D'}{2}\cdot\sqrt{\frac{8\pi F}{A}}=\text{difference of potentials between the two poles of the battery.}$$

It was not necessary to obtain D and D′ separately, D−D′ being given in the difference between the two electrometer readings got by connecting first one pole of the battery and then the other with the lower plate of the electrometer.

The mechanical displacement due to F was determined by a long series of experiments, in which a known weight was distributed over the disk and the displacement of the disk observed. The average result of the later weighings was that 200·55 micrometer-divisions represented the displacement due to a force of ·6 gramme weight. A similar series of observations in the Laboratory of the Old College gave 200·6 as the average displacement. In the comparisons then made 200·6 was employed, but the difference being only that of $\frac{1}{40}$ per cent. is inconsiderable.

II. Electrodynamometer.

Let n, n'=number of turns on the two fixed coils respectively.

r, r'=mean radii of the fixed coils.

b=distance of the mean plane of the fixed coils from the centre of the movable coil, or half the distance of the mean planes from one another.

C=strength of current in the coils.

$2\pi nr$ and $2\pi n'r'$ are the effective lengths of wire in the coils.

Let α and α'=angles subtended at the centre of the movable coil by the radii of the fixed coils.

Then the effective component of the magnetic force at the centre of the movable coil due to the fixed coils is

$$\frac{2\pi nrC}{r^2+b^2}\sin\alpha+\frac{2\pi n'r'C}{r'^2+b^2}\sin\alpha'=C\left\{\frac{2\pi nr^2}{(r^2+b^2)^{\frac{3}{2}}}+\frac{2\pi n'r'^2}{(r'^2+b^2)^{\frac{3}{2}}}\right\}.$$

For each of the coils the following correction for breadth and depth of the coils given by Professor CLERK MAXWELL[*] is to be employed.

---

[*] Electricity, Art. 700.

Let ξ, ξ'=depth of the section of the coils in the plane of the coils,

η, η'=breadth of section of coils perpendicular to the plane of the coils,

then the effective component of the force due to one of the coils is

$$\mathrm{C}\,.\,\frac{2\pi nr^2}{(r^2+b^2)^{\frac{3}{2}}}\left\{1+\tfrac{1}{24}\frac{\xi^2}{r^2}(2-15\sin^2\alpha\cos^2\alpha)+\tfrac{1}{24}\frac{\eta^2}{r^2}(15\sin^2\alpha\cos^2\alpha-3\sin^2\alpha)\right\},$$

and that due to the other

$$\mathrm{C}\,.\,\frac{2\pi nr'^2}{(r'^2+b^2)^{\frac{3}{2}}}\left\{1+\tfrac{1}{24}\frac{\xi'^2}{r'^2}(2-15\sin^2\alpha'\cos^2\alpha')+\tfrac{1}{24}\frac{\eta'^2}{r'^2}(15\sin^2\alpha'\cos^2\alpha'-3\sin^2\alpha')\right\}.$$

For the left coil,

outer radius=16 902 centims., inner radius=15·312 centims.,

r=16·11 centims., ξ=1·59 centim., η=2·00 centims.,

$\sin\alpha=\frac{r}{(r^2+b^2)^{\frac{3}{2}}}$, $\cos\alpha=\frac{b}{(r^2+b^2)^{\frac{3}{2}}}$, and the correcting factor=·9998234.

For the right coil,

r'=16·24 centims., ξ'=1·856 centim., η'=1·95 centim., and the correcting factor =·9997692.

Calling these factors F and F', we have for the magnetic force at the centre of the suspended coil due to the two fixed coils when a current of strength C is passing through them,

$$\left[\left\{\frac{2\pi nr^2}{(r^2+b^2)^{\frac{3}{2}}}\right\}\mathrm{F}+\left\{\frac{2\pi n'r'^2}{(r'^2+b^2)^{\frac{3}{2}}}\right\}\mathrm{F}'\right]\mathrm{C}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The magnetic moment of the suspended coil is equal to the product of the strength of current and the sum of all the areas enclosed by the wire.

Let c=a mean radius of the suspended coil, i=number of turns of wire in the suspended coil,

then $\mathrm{C}\,.\,i\pi c^2$=its magnetic moment, and the couple due to a current C tending to turn the suspended coil round a vertical axis through its centre is

$$\left[\left\{\frac{2\pi nr^2}{(r^2+b^2)^{\frac{3}{2}}}\right\}\mathrm{F}+\left\{\frac{2\pi n'r'^2}{(r'^2+b^2)^{\frac{3}{2}}}\right\}\mathrm{F}'\right]\mathrm{C}^2\,i\pi c^2. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The outer radius of the suspended coil was 5·240 centims., and the inner radius 3·259 centims. The difference of radii, 1·981 centim., being considerable in comparison with the radii themselves, the quantity $i\pi c^2$ was determined experimentally, after the observations had been completed, by a method to be afterwards described. [The result then obtained is used in all the calculated values of v, except those of 1867 and 1868.] The mechanical value of the deflecting couple (2) is given by the equation $\frac{d^2\theta}{dt^2}+\mu\theta=0$, in which $\mu=\frac{\mathrm{E}}{\mathrm{W}k^2}$, $\mathrm{W}k^2$ being the moment of inertia of the coil round a vertical axis, and E the elastic couple per unit angle.

The solution of this equation gives (T=period of vibration of the coil)

$$T=\frac{2\pi}{\sqrt{\mu}}=2\pi\sqrt{\frac{Wk^2}{E}},\ \text{and}\ E=\frac{4\pi^2Wk^2}{T^2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (3)$$

Let γ=strength of current which gives a deflection of one scale-division.

The deflection of the reflected image being twice the deflection of the coil, the elastic couple corresponding to a deflection of one scale-division is

$$E\,.\,\frac{\text{length of 1 scale-division}}{\text{twice distance of scale}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (4)$$

Equating (2) and (4), we have

$$\frac{4\pi^2Wk^2}{T^2}\times\frac{\text{length of scale-division}}{2\times\text{distance of scale}}=\left[\left\{\frac{2\pi nr^2}{(r^2+b^2)^{\frac{3}{2}}}\right\}F+\left\{\frac{2\pi n'r'^2}{(r'^2+b^2)^{\frac{3}{2}}}\right\}F'\right]i\pi c^2\gamma^2. \quad . \quad . \qquad (5)$$

Equation (5) gives γ in terms of units of space, time, and mass. It is seen also from this equation that the deflection produced by a current passing through the coils of the electrodynamometer is proportional to the square of the strength of the current. Accordingly the strength of current indicated by any given deflection is obtained by multiplying the value of γ given in (5) by the square root of the number of scale-divisions in the deflection.

Results of the Comparison.

I. The following is a summary of the results obtained by Mr. King, from a comparison of measurements with the Electrodynamometer and the (old) Absolute Electrometer:—

			centims. per second.
1867.	Nov. 18–27 . .	Electrodynamometer compared with Standard Electrometer, which had been previously compared with the Absolute Electrometer (indirect)	$v=297{\cdot}2\times10^8$
	Dec. 3–20 . .	Direct Comparison of Electrodynamometer and Absolute Electrometer	$v=289{\cdot}2\times10^8$
1868.	Mar. 10–Apr. 7 .	Direct Comparison	$v=284{\cdot}5\times10^8$
	Apr. 20–30 . .	Direct Comparison; observers and all the instruments insulated	$v=283{\cdot}7\times10^8$
	May 1–10 . .	Direct Comparison	$v=285{\cdot}6\times10^8$

Mean value of v given by this comparison, leaving out the two first sets (which were taken under very unfavourable circumstances), is $284{\cdot}6\times10^8$ centims. per second.

II. The comparisons which were made during March 1870 in the Laboratory of the old College were preceded by some alterations in the electrodynamometer, and a fresh determination of several of the quantities connected with it. Resistances were measured by a new set of standard coils, and the old absolute electrometer was superseded, in the comparison, by the new absolute electrometer already referred to.

The movable coil was resuspended, and a light mirror, the opposite sides of which had been ground parallel, was substituted for the heavier mirror that had been formerly used.

The moment of inertia of the vibrator with which the coil was compared was 4307·498 centimetre-grammes.

The periods of vibration of coil and vibrator similarly suspended were 4·69 and 7·795 seconds respectively. Whence for the coil

$Wk^2=4307\cdot498\times(\frac{4\cdot69}{7\cdot795})^2=1559\cdot3$ centimetre-grammes.

Addition for cross piece	=	0·2	„	„
Total moment of inertia	=	1559·5	„	„

Period of vibration of coil after being suspended in the electrodynamometer was $T=4\cdot800$ seconds.

Distance of scale=446·5 centims.

Length of each scale-division $=\frac{1}{40}$ inch $=\frac{2\cdot539954}{40}$ centims.

Number of turns on left-hand coil, $n=3720\cdot75$.

Number of turns on right-hand coil, $n'=3668\cdot50$.

Mean radius of left-hand coil, $r=16\cdot11$ centims.

Mean radius of right-hand coil, $r'=16\cdot24$ centims.

Distance of mean plane of coils from centre of the suspended coil, $b=8\cdot185$ centims.

$i\pi c^2$ (determined by experiment May 10, 1872)=195,420 sq. centims.

These values being substituted in equation (5), for this series of observations $\gamma=\cdot000021842$ electromagnetic units.

The following Tables exhibit results obtained from simultaneous measurements of current and electromotive force. It would have been desirable to have had more frequent measurements of the resistance of the coils; but as only two observers were generally available, and the comparison of the electrodynamometer and electrometer required the attention of two observers, this was not generally practicable. There was always a liability in the coils to a variation in resistance, due to the variation in the temperature of the coils caused by the current; but as the current was not allowed to pass through the coils for a longer time than was just necessary for its measurement, these variations were not considerable.

The plan of the connexions is indicated in Plate XXXII. fig. 4. Two terminals were led from the battery (B) to a reversing key (K). The wires leading from the key were connected one to the end of the left-hand coil (A′), the other to the opposite end of the right-hand coil (A). From these points, where the battery joined the electrodynamometer coils, electrodes were brought to another reversing key (C) which was connected with the absolute electrometer (E), one of its wires being connected with the insulated electrode of the electrometer which communicated with the insulated lower plate, the other being in contact with the outside coating of the jar of the electrometer. The difference of potentials thus measured was not the entire difference of potentials between the two poles of the battery, but the reduced difference maintained between the extremities of the electrodynamometer circuit.

When two deflections, with the current passing in opposite directions, had been read off on the electrodynamometer scale, the mean between these two deflections was taken as representing what would have been the deflection supposing that the process of eliminating the horizontal component of the earth's magnetism had been perfectly successful. These deflections are noted as R. and L. (right and left) with reference to the sides of the battery-key. Corresponding to each, two readings were obtained in the absolute electrometer by reversing the electrometer-key while the battery-circuit continued "made," half the difference of readings due to this reversal representing the difference of potentials between the two ends of the coils through which the current was passing.

It was found, however, in most of the comparisons, that the current corresponding to a difference of potentials sufficiently large to be measured on the electrometer with a small percentage of error, produced a deflection in the electrodynamometer beyond the limits of the scale.

In order to reduce the strength of current without at the same time reducing the difference of potentials to be measured by the electrometer, a large resistance (R), generally equal to that of the circuit formed by the coils, was introduced between the coils and the battery, and the difference of potentials between one extremity of this interpolated resistance and the remote end of the coils was observed. From this the difference of potentials between the two ends of the coils was immediately deducible.

Temp. 8°·2 C. March 11, 1870. Battery 180 cells.

Electrometer.		Electrodynamometer.		Resistance in B. A. units. $1=10^9$ centims. per second.	*v* in centims. per second.
Difference.	Mean.	Deflection.	Mean.		
63·3	63·2	R. 420·5	420·75	15587	293·0 × 10^8
63·1		L. 421·0			
63·4	63·4	L. 420·5	420·5	(15597)	292·2 × 10^8
63·4		R. 420·5			
63·1	63·2	L. 420·0	419·5	15607	292·3 × 10^8
63·3		R. 419·0			

Temp. 9°·4 C. March 15, 1870. Battery 180 cells.

Electrometer.		Electrodynamometer.		Resistance in B. A. units. $1=10^9$ centims. per second.	*v* in centims. per second.
Difference.	Mean.	Deflection.	Mean.		
61·5	61·45	R. 412·0	410·25	15555	297·0 × 10^8
61·4		L. 408·5			
61·8	61·90	R. 410·0	409·25	....	294·5 × 10^8
62·0		L. 408·5			
61·7	61·55	R. 409·0	408·25	....	295·8 × 10^8
61·4		L. 407·5			

Temp. 9°–9°·7 C. March 16, 1870. Battery 180 cells.

Electrometer.		Electrodynamometer.		Resistance in B. A. units. 1=10^9 centims. per second.	v in centims. per second.
Difference.	Mean.	Deflection.	Mean.		
61·7	61·75	R. 424·0	417·5	15342	$294\cdot0\times10^8$
61·8		L. 411·0			
61·1	60·90	R. 420·0	414·0	(15372)	$297\cdot5\times10^8$
60·7		L. 408·0			
61·3	61·35	R. 419·5	413·25	(15402)	$295\cdot6\times10^8$
61·4		L. 407·0			
61·4	61·25	R. 417·0	411·5	(15432)	$295\cdot8\times10^8$
61·1		L. 406·0			
61·3	61·10	R. 416·0	414·5	(15462)	$298\cdot4\times10^8$
60·9		L. 413·0			
61·3	61·25	R. 417·0	411·0	(15492)	$297\cdot0\times10^8$
61·2		L. 405·0			
61·5	61·35	R. 417·5	412·75	15522	$297\cdot7\times10^8$
61·2		L. 408·0			

The resistance of the coils was measured at the beginning and at the end of this series. The intermediate values of the resistance are inserted on the supposition of a gradual increase in the resistance of the coils.

The suspending-wire having been soldered to the brass cover to which it had been attached, the period of vibration of the coil was found to be 4·789 seconds; so that, for succeeding observations, $\gamma=\cdot000021884$.

At this stage an attempt was made to use simultaneous measurements made by means of the old and new absolute electrometers; but this method was not carried out, chiefly on account of difficulties in the use of the old absolute electrometer arising from imperfect insulation and other causes. The former method of comparison simply with the new absolute electrometer was resumed.

Temp. 10°·8 C. March 22, 1870. Battery 180 cells.

Electrometer.		Electrodynamometer.		Resistance in B. A. units. 1=10^9 centims. per second.	v in centims. per second.
Difference.	Mean.	Deflection.	Mean.		
61·15	61·22	R. 391·25	391·4	15654	$293\cdot6\times10^8$
61·3		L. 391·5			
61·1	60·95	R. 389·5	389·25	....	$294\cdot0\times10^8$
60·8		L. 390·0			

Temp. 14°·8 C. March 23, 1870. Battery 180 cells.

Electrometer.		Electrodynamometer.		Resistance in B. A. units. $1 = 10^9$ centims. per second.	v in centims. per second.
Difference.	Mean.	Deflection.	Mean.		
60·0 59·4	59·70	R. 372·5 L. 370·5	371·5	15617	$292·6 \times 10^8$
58·7 58·7	58·70	R. 367·5 L. 367·0	367·25	15633	$295·9 \times 10^8$
60·0 59·1	59·55	R. 367·5 L. 365·5	366·5		$291·7 \times 10^8$
59·0 58·9	58·95	R. 364·0 L. 364·0	364·0	15658	$293·6 \times 10^8$
59·0 59·0	59·00	R. 363·75 L. 362·75	363·25	15673	$293·5 \times 10^8$
59·0 59·0	59·00	R. 361·0 L. 361·5	361·25		$293·0 \times 10^8$

The figures in the electrometer and electrodynamometer columns of the above Tables represent the readings in the arbitrary divisions of the two instruments. To deduce the value of v, these readings were reduced to absolute measure by means of the expressions for $V-V'$ and γ already given. The resistance introduced into the circuit being equal to that of the coils, half the difference of potentials indicated by the electrometer was employed in the calculations.

III. The instruments having been removed to the new laboratory, were again set up in the spring of 1871, but no observations were made till September following.

When the electrometer was set up, a series of weighings was gone through to determine the displacement of the movable disk produced by a given force. A long series of weighings of May 15th and 16th gave 200·19 micrometer-divisions as the displacement due to ·6 gramme. Before the electrometer was again used in September a longer series of weighings was gone through: this gave as the mean value of the displacement 200·55 divisions, and this value was adopted in succeeding measurements.

The electrodynamometer was set up in the same manner as formerly; the only alteration was in the manner of adjusting the lamp and lens, which were now supported and adjusted in the manner already described. A new determination was made of the moment of inertia of the suspended coil: this had become necessary from an alteration in the weight of the coil arising from the loss of a part of the mirror.

The moment of inertia of the vibrator with which the coil was compared was 4293·772 centimetre-grammes. The periods of vibration of the vibrator and coil were 25·939 and 15·5575 seconds respectively. This gave as the moment of inertia of the suspended coil 1544·6036 centimetre-grammes. After this comparison the mirror of the coil was resilvered, and was found to have increased in weight ·101 gramme. With this increase of weight the moment of inertia of the coil became 1544·704 centimetre-grammes. The distance of the scale was made 354·6 centims. The period of vibration of the coil was 5·823 seconds. With these alterations the value of γ became ·000020114.

Temp. 17° C. September 12, 1871. Battery 90 cells.

Electrometer.		Electrodynamometer.		Resistance in B. A. units. $1=10^9$ centims. per second.	v in centims. per second.
Difference.	Mean.	Deflection.	Mean.		
36·25	36·25	R. 647·5	647·5	15960	$298·8\times10^8$
36·25		L. 647·5			
36·25	36·27	R. 646·75	646·75	....	$298·5\times10^8$
36·3		L. 646·75			

September 16, 1871. Battery 90 cells.

Electrometer.		Electrodynamometer.		Resistance in B. A. units. $1=10^9$ centims. per second.	v in centims. per second.
Difference.	Mean.	Deflection.	Mean.		
35·1	35·1	R. 608·5	611·0	(15960) assumed from former measurements.	$299·8\times10^8$
35·1		L. 613·5			
35·6	35·0	R. 602·5	601·5		$298·3\times10^8$
34·4		L. 600·5			
34·3	34·8	R. 616·0	614·5	....	$303·9\times10^8$
34·8		L. 613·0			
35·25		R. 615·5	615·0	....	$293·2\times10^8$
36·6	36·0	L. 614·5			
35·4		R. 613·5	613·5	.. ..	$297·0\times10^8$
35·4	35·5	L. 613·5			
35·55		R. 613·5	614·25	....	$295·5\times10^8$
35·6	35·7	L. 615·0			
35·8					

A considerable degree of uncertainty attaches to the foregoing results on account of their variations amongst themselves, and also because an independent determination of the resistance of the coils was not made. The variations are due chiefly to variations in the electrometer readings, to which there was the greater liability on account of the smallness of the difference of potentials measured. A battery of 90 cells was employed, no additional resistance having been introduced into the circuit.

In the series which follow a continuous measurement of resistance was made. The same battery was used, but the differences of readings in the electrometer show less variation among themselves. The period of vibration of the coil was 5·811 seconds, and the corresponding value of γ ·00002015.

September 22, 1871. Battery 90 cells.

Electrometer.		Electrodynamometer.		Resistance in B. A. units. $1=10^9$ centims. per second.	v in centims. per second.
Difference.	Mean.	Deflection.	Mean.		
33·45 33·3	33·37	R. 542·25 L. 544·25	543·25	15825	295·4 × 10^8
34·0 33·85 33·95	33·93	R. 545·75 L. 542·25	544·00	15805	290·3 × 10^8
34·0 33·8 33·3	33·70	R. 543·75 L. 545·0	544·37	15810	292·5 × 10^8

September 24, 1871. Battery 90 cells.

Electrometer.		Electrodynamometer.		Resistance in B. A. units. $1=10^9$ centims. per second.	v in centims. per second.
Difference.	Mean.	Deflection.	Mean.		
34·25 34·0	34·12	R. 551·0 L. 550·5	550·75	15840	291·1 × 10^8
34·0 34·1 34·0 34·0	34·02	R. 552·5 L. 551·25	551·87	15834	292·2 × 10^8
33·75 33·9 34·0 33·9	33·88	R. 551·75 L. 550·75	551·25	15832	293·2 × 10^8

September 25, 1871. Battery 90 cells.

Electrometer.		Electrodynamometer.		Resistance in B. A. units. $1=10^9$ centims. per second.	v in centims. per second.
Difference.	Mean.	Deflection.	Mean.		
35·5 35·25 35·2	35·32	L. 601·0 R. 602·0	601·5	15728	291·8 × 10^8

September 26.—The period of vibration of the suspended coil was observed and found to be 5·805 seconds. The corresponding value of γ was ·000020175.

Electrometer.		Electrodynamometer.		Resistance in B. A. units. $1=10^9$ centims. per second.	v in centims. per second.
Difference.	Mean.	Deflection.	Mean.		
32·9 33·0 32·75 32·8	32·86	R. 523·0 L. 522·5	522·75	15640	291·3 × 10^8

September 28, 1871. Battery 90 cells.

Electrometer.		Electrodynamometer.		Resistance in B. A. units. 1 = 10^9 centims. per second.	v in centims. per second.
Difference.	Mean.	Deflection.	Mean.		
33·2 33·5	33·35	R. 536·5 L. 536·5	536·5	15715	292·0 × 10^8
32·85 32·8 32·5	32·79	L. 529·5 R. 526·5	528·0	15715	294·6 × 10^8
33·0 32·7 33·1 32·7	32·81	L. 518·25 R. 518·25	518·25	15711	291·6 × 10^8
32·8 32·75 32·6 32·5 32·4 32·8	32·63	R. 520·0 L. 518·5	519·25	15722	293·7 × 10^8
32·8 32·5 32·8					

No further comparisons were made till February 21, 1872. In the series of observations then taken, to secure a greater difference of readings in the electrometer, a larger battery was employed, and a resistance of 10,000 ohms was introduced into the circuit. The difference of potentials between the ends of the coils was thus $\frac{R}{R+10,000} \cdot e$, where e represents the difference of potentials read off in the electrometer, and R is the resistance of the electrodynamometer circuit.

The scale was removed to a greater distance, 367·9 centims., and the period of vibration of the coil was 5·819 seconds. The corresponding value of γ was ·000019761.

The resistance of the coils at the observed temperature was afterwards measured and found to be 15834 B. A. units. This value of R is used in the calculations.

Temp. 15° C. February 21, 1872.

Electrometer.		Electrodynamometer.		Resistance in B. A. units. 1 = 10^9 centims. per second.	v in centims. per second.
Difference.	Mean.	Deflection.	Mean.		
58·0	58·00	R. 630·5 L. 633·5	632·00	15834	293·4 × 10^8
58·1 58·1	58·10	L. 636·0 R. 633·5	634·75	....	293·5 × 10^8
58·2 58·3	58·25	L. 638·25 R. 634·5 L. 634·0	636·19	....	293·1 × 10^8
58·4	....	R. 634·0 L. 638·0 R. 634·25	636·12	....	292·3 × 10^8
58·2	....	R. 635·0 L. 638·25	636·62	....	293·5 × 10^8
58·2	....	L. 638·5 R. 635·0	636·75	....	293·5 × 10^8

Determination of the Area of the Movable Coil.

Before unwinding the coils for the purpose of measuring the length of the wire, and counting the number of turns in each coil, a comparison of the large coils and the suspended coil was made to determine the magnetic moment of the latter. This quantity, which appears in the calculations as $i\pi c^2$, could not be obtained very accurately by measurement of the outer and inner radii of the coil, seeing that the difference between these radii was very considerable in comparison with either.

The method of comparison followed was suggested by Professor CLERK MAXWELL. The simultaneous action of the large coils and the smaller coil upon a magnet placed in their neighbourhood was observed. The distances between the coils and the magnet being so arranged that the simultaneous action of the opposing coils upon the magnet was zero, and these distances being known, the ratio between the areas of the coils was easily obtained. The chief difficulty being to measure accurately these distances, two symmetrical observations were made with the smaller coil on opposite sides of the magnet. The distance between the positions of the same part of the coil in these two observations was measured, and half this distance taken as the distance of the centre of the coil from the magnet in each position.

The coils (see Plate XXXII. fig. 5) rested upon a narrow table (t) which had been prepared for this comparison. A V-groove (v) ran from end to end of it parallel to its edge, near one side, to guide the adjustment of the magnet and smaller coil. The stands (s, s') to which the large coils had been attached were placed at opposite ends of the table, and were so adjusted that the line joining the centres of the coils passed through the centre of the magnet.

The magnet (m), which had been used as a declinometer, was suspended by a long fibre in an enclosed space. It carried a light galvanometer-mirror, whose motions were visible through a small lens, which formed part of the glass front of the instrument. The declinometer, two of its feet resting in the V-groove, was placed between the coils, so that the centre of the mirror or magnet was equidistant from the centres of the large coils. The "suspended" coil, supported on a wooden stand (p), was placed between the magnet and one of the large coils, its motions to and from the magnet being guided parallel to itself by the groove in which two of the feet of the stand rested: it was adjusted so that its centre also should be in the line joining the centres of the large coils. The three coils were arranged so as to have their planes parallel, and so that the action of the two large coils should conspire to oppose the action of the smaller coil, which was placed much nearer the magnet. The motions of the magnet were observed in the usual manner, by reflection from the mirror. A current from a battery of 120 cells was made to pass through the three coils in series. The smaller coil was moved to and fro parallel to itself until no deflection of the magnet could be detected. During this observation it was found that the magnet was sensitive to the smallest motion of the coil that was appreciable.

The position of the coil with reference to the table was noted by marking on the table the position of the front and of the back of the stand.

The coil was then transferred to the other side of the magnet, and a similar observation made. The distance between the two positions of the coil was found to be 42·221 centims. Accordingly 21·11 centims. was taken as the distance of the centre of the smaller coil from the magnet in each observation. The distance between the centres of the large coils, measured directly, was 131·48 centims.; so that the distance of the centre of each from the magnet was 65·74 centims.

Calling these distances a and b respectively, we have, for zero deflection, the following equation:—

$$\frac{2\pi n r^2}{(r^2+b^2)^{\frac{3}{2}}}\cdot \mathrm{F}+\frac{2\pi n' r'^2}{(r'^2+b^2)^{\frac{3}{2}}}\mathrm{F}'=\frac{2i\pi c^2}{(c^2+a^2)^{\frac{3}{2}}}.$$

This is a cubic equation in c^2, and the solution of it would yield c^2 in terms of the known quantities n, n', r, r', a, b, &c. Two of the roots of this equation are imaginary, the coefficient of c^2, when the equation is reduced to the typical form, $x^3+qx+r=0$, being positive.

Without going through the ordinary process of solution to find the third root of this equation, which from the complicated form of the coefficients in this case is not convenient, c can be readily found by the following method of approximation. c is approximately known by measurement, and i, the number of turns of wire in the coil, is also known. Assuming this value of c in $(c^2+a^2)^{\frac{3}{2}}$, $2i\pi c^2$ is given by the equation. Substituting the value of i in this result, a new value of c is obtained. Using this new value of c, by means of the equation we obtain a new value for $2i\pi c^2$, and so on through several approximations.

Thus, starting with $c=4·3$ centims., we find for $i\pi c^2$ the successive values 195681, 195435, 195421, 195420 square centims., with the corresponding values of c 4·25427, 4·2516, 4·25144, and 4·25143.

Starting with a value of c on the other side of this limit, $c=4·25$, we find for $i\pi c^2$ 195412, 195419, with the corresponding values of c 4·25135, 4·25143. The value of $i\pi c^2$, 195420, has been adopted in the calculations.

When the comparison of the coils had been completed, the wire was unwound from the coils. The resistance of the wire was measured before unwinding, and also after unwinding, to test for short-circuiting.

Before unwinding (temp. 13° C.) the resistance of the wire of the right coil was 5630 ohms, after unwinding (temp. 14°·1 C.) 5654 ohms, the rise of temperature being sufficient to account for an increase of resistance of about 20 ohms.

The resistance of the wire of the left coil before unwinding (temp. 11°·75 C.) was 5705 ohms, after unwinding (temp. 14°·1 C.) 5726 ohms.

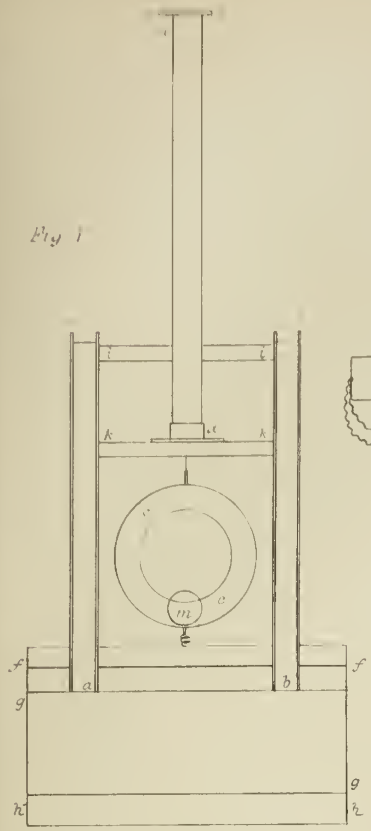
From this comparison of resistance it may be inferred that the insulation in the coils was very nearly perfect, that the effective length of the wire was that due to all the turns in each of the coils, and that the estimate of their electromagnetic effect derived from this was as nearly as possible accurate.

The mean value of v given by all the series of observations of 1870, which include, however, considerable variations, is $294{\cdot}5 \times 10^8$ centims. per second. The mean result of the later comparisons, excluding those which have been mentioned as less trustworthy, is $292{\cdot}4 \times 10^8$ centims. per second.

These later observations were made under much more favourable circumstances; still, as the causes of the variations in the earlier comparisons are not known, it has been thought right to include them also in the record of the observations.

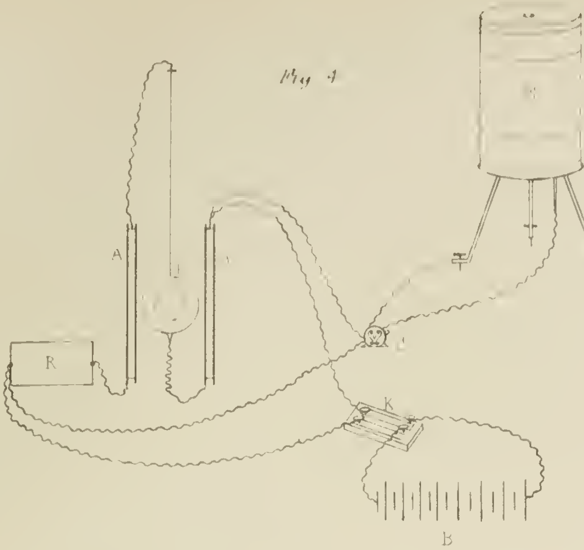
The last measurement, that of 1872, furnishes the most probable value of v, 293×10^8 centims. per second.

Fig 1



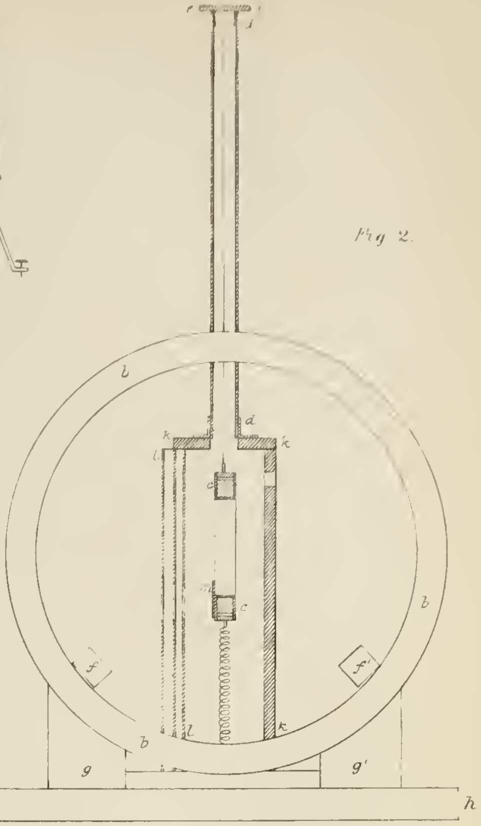
Electrodynamometer-Front elevation.
Front of Box removed to shew Suspended Coil.

Fig 4



A. Right Fixed Coil
A'. Left " "
D. Suspended "
R. Resistance
E. Electrometer
C. Electrometer Key
B. Battery
K. Battery Key

Fig 2.



Electrodynamometer Side elevation (Box & Suspended Coil shewn in section

Fig 5

Comparison of Areas of the coils

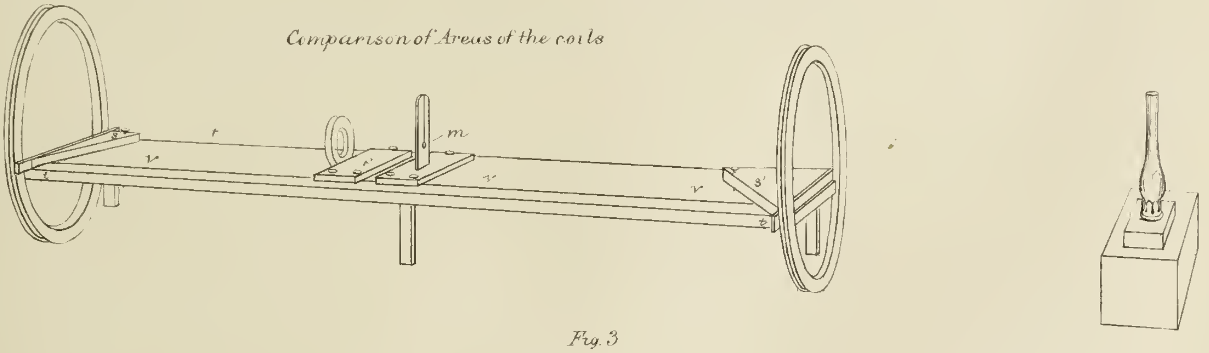
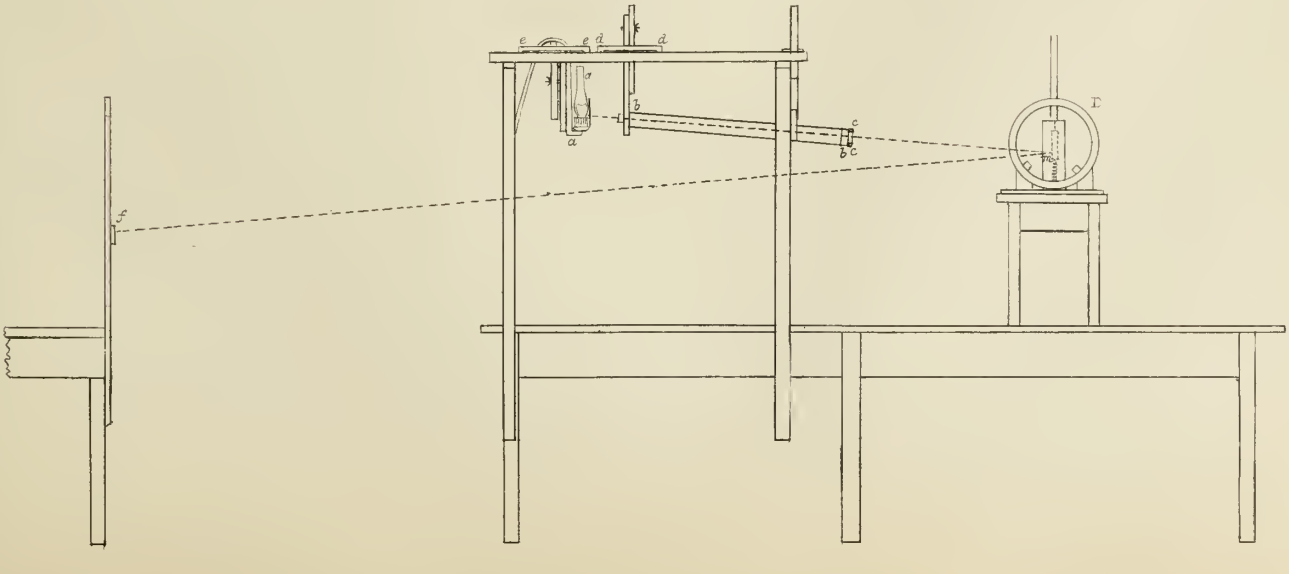


Fig. 3



W H Wesley lith.
W. West & Co imp.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

XII. *On the Minute Structure of the Leg-muscles of the Water-beetle. By* Edward Albert Schäfer. *Communicated by* Dr. Sharpey, *V.P.R.S.*

Received March 13,—Read April 3, 1873.

For the successful prosecution of the histological inquiry which forms the subject of the present communication, it is essential that the tissue to be investigated should be studied whilst still in the living condition, inasmuch as marked changes ensue very speedily after the death of the muscle, and still more speedily on the addition of reagents, even the so-called indifferent fluids, such as serum or $\frac{1}{2}$ per cent. solution of common salt, being in this case inadmissible. The description, therefore, I have now to give is founded entirely on an examination of the living tissue.

I. *Appearance of Living Muscle in the state of rest.*

If we cut off a limb from one of the common large Water-beetles (*Dytiscus marginalis*), remove a portion of muscle from the upper part, quickly separating the fibres somewhat from one another, by means of needles, on a glass slip, cover it without addition, and examine the preparation so obtained with the aid of a very powerful immersion-objective (such as the No. 11 of Hartnack or the No. 3 of Zeiss), we find numerous muscular fibres presenting an appearance similar to that represented in Plate XXXIII. fig. 1.

The well-known transverse bands are conspicuously seen, consisting of broader dim* stripes (*a a*) alternating with narrower bright ones (*b b*), the latter exhibiting a transverse line of minute dots (*c*). These bands are now very generally admitted to represent disks composed of two entirely distinct substances, arranged in successive series with their planes at right angles to the axis of the fibre; and I shall, for convenience of description, adhere for the present to this notion, although, as I shall afterwards endeavour to show, the difference in appearance which they present may be accounted for otherwise than by regarding them as composed of different materials.

To proceed with my description. Each disk of dim substance appears pervaded throughout by a number of excessively fine rod-shaped particles of uniform diameter, and rather darker in appearance than the substance of the disk which they traverse. These particles are arranged closely and very regularly, with their axes in a direction more or less parallel to that of the fibre; they extend at either end into the neighbouring disks of bright substance, becoming somewhat less distinct as they pass into this, and finally terminating near its middle in an enlarged knobbed extremity, which appears as a minute dark dot. Consequently each of the bodies we are now considering, and which from their form may be denominated *muscle-rods*[*], may be described as consisting of a cylindrical middle part or *shaft*, which is imbedded in the substance of the dim stripe, and of two enlarged extremities or *heads*, which are found near the middle of the bright stripe. It further follows that there are as many series of muscle-rods as disks of dim substance in the fibre. Moreover each rod of any one series corresponds exactly with one in the next following series, their enlarged extremities almost meeting in the middle of the bright substance; this arrangement causes the appearance of a double row of dots (*c*) running transversely across each bright stripe[†].

---

* I use the word "dim" because, in fact, in living muscle at rest no such thing as a *dark* stripe occurs; one part is only somewhat less bright than the other.

It must be observed, however, that in such a preparation as is here spoken of, the appearance represented in the figure, although very common, is by no means the only one that presents itself. All the variations, however, that are met with are accompanied and, as will be hereafter shown, in all probability caused by variations either in the relative position or in the form of the muscle-rods. Thus we not unfrequently find fibres in which the rod-heads of contiguous series, instead of being in more or less close apposition in the middle of the bright disk, are separated by a distinct bright interval; this is more especially the case when the muscular fibre happens to be somewhat stretched.

Sometimes a greater or less number of the rods of neighbouring series are shifted abruptly upon the rest in a longitudinal direction, so much so that their heads may come to be opposite the middle of the shafts of the remainder (see fig. 1). In such cases the transverse striæ also become correspondingly shifted. This fact would of itself almost preclude the conception of the existence of continuous membranes extending across the fibre, an idea which has been largely prevalent of late years.

The variations which occur in the *form* of the muscle-rods are chiefly, if not entirely, dependent upon the relation in size which subsists between the shafts and the ends, these seeming to be in inverse ratio with one another. Thus the shafts are not unfrequently increased in length, the heads at the same time becoming smaller and closer to those of the next series, so that a double row of dots is no longer seen in the middle of the bright stripe, having become merged into a single dark transverse streak, having a granular look.

---

[*] A word here seems due to explain why the use of the term "sarcous elements"—which was applied by Mr. BOWMAN ("On the Structure and Movements of Voluntary Muscle," Phil. Trans. 1840) to the minute particles of which he conceived a muscular fibre to be composed, and which has been very generally applied by subsequent observers, both here and on the Continent, to the rod-like bodies which are commonly described in the muscles of insects—has been omitted throughout the present communication. The reason is simply this—that the term is ordinarily understood to imply that the bodies to which it is applied form the essential contractile constituent of muscle, whereas it will be seen from what follows that this is probably not the case with the structures here denominated muscle-rods. It should, however, be distinctly understood that the latter term is employed to signify simply the *form*, without reference to the nature of the material of which the particles in question are composed.

[†] Compare STRICKER, 'Handbuch der Gewebelehre,' p. 1225.

If we imagine this process to go on still further—that is to say, if the shafts go on increasing in size at the expense of the rod-heads until each muscle-rod is of uniform diameter throughout, the ends of the rods of different series being in close apposition, it may well be imagined (the smallness of the objects with which we have to deal being taken into consideration) that it will be extremely difficult to detect the points of junction between the rods of successive series. In this way the continuous longitudinal fibrillation which is often seen in the muscles of the Water-beetle may be accounted for. That each fibril, however, is not in reality continuous throughout the fibre, but consists of a succession of shorter units, the ends of which are in close apposition, is shown, not only by the phenomena which occur when such a muscular fibre is thrown into contraction, and which will be referred to further on, but also by the appearances presented when a portion of the fibre comes under observation in which these units are thrown into zigzag instead of lying in the same straight line, in which case the angles of the zigzag represent the points of junction of the muscle-rods.

It is worthy of note that in all fibres like that we are now considering (that is to say, all in which the rod-heads are of the same diameter as the shaft, so as no longer to appear as distinct objects), the bright transverse bands have entirely disappeared, and the substance between the rods is of a uniform appearance throughout.

II. *Appearance of Contracted Muscle.*

In contracted muscle (fig. 2, C) we observe, besides the general increase in thickness of the fibre and the approximation of the cross striæ, that the latter have become completely altered in character. Dark and light transverse stripes now appear, which are of nearly equal size: the former, instead of being merely dim as in the resting muscle, have a decidedly dark aspect; the light stripes, on the other hand, present a very bright appearance, without any indication of a row of dots, but with sometimes a faint longitudinal streaking.

In order to explain this difference between a fibre at rest and the same fibre in the contracted state, it is necessary to follow all the stages of the process. Owing to the extreme suddenness and rapidity with which the contraction supervenes, and the amount of displacement which immediately precedes and accompanies it, it becomes a matter of exceeding difficulty to follow the details of the process with the high powers which it is necessary to employ. However, it has occasionally happened to me to observe a contraction proceeding at a very much less rapid rate, and in such cases it was possible to make out the following changes:—

The first thing seen is that the bright transverse bands become approximated throughout the contracting portion (P), and with them the dark transverse lines in their middle, which, as previously shown, are made up of a double row of dots (rod-heads). As the contraction continues the rod-heads become larger, and by this means are brought into close relation with the neighbouring ones, so that each double line of dots (c) no longer appears as such but as a single dark transverse band ($c_{,}$), which separates the bright stripe ($b_{,}$) into two distinct parts. As these dark transverse bands approach one another, their bright borders encroach more and more upon the dim stripe ($a_{,}$), until this becomes reduced to a mere line, and finally disappears altogether: so that in contracted (C), as compared with resting muscle, the broad dim stripes (a) are replaced by bright bands ($b_{,,}$), the clear stripes (b) by dark bands ($c_{,,}$), these last being the optical sections of the disks which are formed throughout the fibre by the close juxtaposition of the enlarged rod-heads; the shafts of the rods have become much finer than before, so as to be hardly perceptible as they cross the now bright transverse bands.

III. *Transverse Section.*

When a small portion of living muscle is quickly teazed out upon a slip of very thin glass, to which it remains adherent, and the glass is then inverted over a ring of putty on an object-slide, so that the preparation is enclosed in an atmosphere which is saturated with moisture (STRICKER's moist chamber), we are sometimes fortunate enough, in examining it, to find one or more fibres which are bent upwards near the end, and of which consequently we get a view of the transverse optical section (fig. 3). Employing the No. 11 HARTNACK we observe the following:—

The cross section of the fibre appears of a rounded or somewhat oval form, enclosed by a distinct contour line (section of the sarcolemma), and with a small granular mass in the centre (central protoplasm), which may be almost entirely occupied by one or more nuclei. The area of the section between the sarcolemma and the central protoplasm has a minutely punctuated character, this appearance being due to the presence of a number of minute specks scattered equally over the field; the intervals between them appear homogeneous, clear, and bright. This appearance is obtained to whatever depth in the fibre we focus the microscope. As far as can be made out, these specks correspond with the rods which are seen in longitudinal view. The substance in which they are imbedded is quite similar in aspect to that which composes the bright transverse disks (fig. 1, b); why the dim substance in which, in longitudinal view, the shafts of the rods appear to be imbedded is not seen, as least as such, in the transverse section will become evident when we have treated of the production of the cross striæ.

IV. COHNHEIM's *Areas.*

If, in order to obtain the transverse view of a muscular fibre, we employ the method recommended by COHNHEIM* (that is to say, if we make a cross section of the frozen muscle and examine it in a so-called indifferent fluid, such as the ½ per cent. solution of salt), we sometimes obtain the appearance described by him of dim polygonal areas, bounded by and enclosed in a network of clear bright lines. It would seem probable, however, that these areas are due to the action of the saline solution; for, as KÖLLIKER[*] has pointed out, they do not occur if the section is examined fresh without addition. A fine punctuation has been described within COHNHEIM'S areas[†]; this is, however, better seen when the limits of the areas are less marked.

---

* "Ueber den feineren Bau der quergestreiften Muskelfaser," VIRCH. Arch. Bd. xxxiv. (1865).

It is but seldom that I have been successful in obtaining COHNHEIM'S areas in sections of *Dytiscus*-muscle. On the other hand, it is not at all uncommon to find fibres the section of which presents the appearance of dark lines, with bright intervals, radiating from the central protoplasm (fig. 4). The lines are equidistant from one another, and now and then divide dichotomously as they proceed outwards towards the sarcolemma. The picture presented irresistibly brings to mind the appearance of a transverse section of an incisor tooth as seen with a low power. The addition of fluid is not necessary for the production of this appearance, as seems to be the case with the areas of COHNHEIM.

As regards an explanation of these appearances, I am inclined to think that the section becomes mapped out into areas of COHNHEIM owing to a change which takes place in the intermediate substance between the muscle-rods, whereby, instead of being evenly diffused, this tends to collect at definite lines in the fibre, the rods which are enclosed by these becoming on this account more closely grouped, so as eventually to be no longer separately distinguishable.

The radiated appearance above described I was at one time inclined to explain in a similar manner; it may, however, be due to a slight inclination of the muscle-rods towards the axis of the fibre; in this manner they would appear to overlap one another, and so produce the effect of radiating lines.

V. *Ground-substance of Muscle—Cause of the Cross Striæ.*

The muscle-rods do not form by their agglomeration the muscular fibre, but are distinctly seen to be imbedded in a *ground-substance*, the characters of which we must now discuss.

This substance appears, as a rule, in longitudinal view not homogeneous, but, as before mentioned, to consist of alternating disks composed of two distinct materials, of which the one in which the heads of the muscle-rods lie is bright and clear, whereas that which contains their shafts is dim. The fact that the bright transverse bands are often seen to present a slight bulging opposite each of the rod-heads, and that when the latter become of the same diameter as the shaft (so as to be no longer seen as distinct objects) the bright bands also entirely disappear, would seem to show that the bright appearance is an optical effect produced by the presence of the globular heads.

That such an explanation is a possible one is shown by the following experiment:—

A strong solution of gelatine is taken, and having been rendered fluid by heat, a few drops of oil are added and the mixture is thoroughly shaken for a few minutes. By this means the oil becomes suspended in the gelatine in a state of extremely minute subdivision. If, after the mass has congealed, we make a thin section from the middle with a razor, and in the section so obtained examine the minute oil-globules with a high power, they are seen as dark dots each surrounded with a bright halo *. If we happen to come across several such little oil-globules, arranged in a row close to one another, we obtain the appearance of a line of dots in the centre of a bright band.

---

[*] "Ueber die COHNHEIM'SCHEN Felder der Muskel-Querschnitte," Zeitschr. f. wiss. Zool. Band xvi. (1866).

[†] KÖLLIKER, *loc. cit.* ENGELMANN, "Mikroskopische Untersuchungen über die quergestreifte Muskelsubstanz," PFLÜGER'S Archiv, Jan. 1873.

The bearing of this simple experiment upon the production of the well-known cross striæ of muscle is obvious. For in a muscular fibre there are regularly arranged rows of minute spheroids (the globular rod-heads), the optical effect of which may be conceived to be quite similar to that of the minute oil-globules in our experiment, viz. to make the substance in which they are imbedded appear brighter in their immediate neighbourhood than it would otherwise be; by this means we obtain the appearance of the bright bands crossing the ground-substance, which have been described by all previous observers, with the exception of HEPPNER† (with whom DÖNITZ‡ would seem to agree in this respect), as constituted by a distinct substance.

It is further to be noted that the neck of each muscle-rod, the part where the head joins the shaft, is comparatively indistinct; this is due to the optical effect produced by the proximity of the globular head, and is contrary to what one would be led to expect if we assume this part of the rod to be imbedded in a clearer substance than the rest, for in such a case it would stand out the darker by the contrast. To this it is probably owing that previous observers have very generally failed in noticing the connexion of the row of dots with the rods.

The appearance of a transverse section is corroborative of the view here taken of the production of the bright bands; for in this case the dots are seen sufficiently close together for the optical effect produced upon the ground-substance by any one of them to be merged into that of the neighbouring ones, so that the intermediate substance appears uniformly bright.

The close relation subsisting between the rows of rod-heads and their bright borders is also seen when a muscle contracts, the movements of the one proceeding *pari passu* with those of the other.

A further indication that the whole of the ground-substance is of the same nature is to be found in the fact that, as will immediately be shown, it exhibits towards polarized light a similar behaviour throughout.

In the state of rest this ground-substance pervades the whole muscular fibre; in contraction, however, it seems to tend more towards the middle of the muscle-rods between their shafts, thus producing bulgings at the exterior of the fibre opposite these.

---

* This appearance occurs both when the globules are in focus and also when they are slightly out of the focus; the surrounding brightness may be sometimes seen to be pretty sharply bounded by a margin, which is dimmer than the rest of the field. I am inclined to believe this to be an effect due to the interference between the rays of light which are reflected from the surface of the globule and those which are refracted through its substance. Its bearing upon certain appearances sometimes observed in muscular fibres will be noticed later on.

† "Ueber ein eigenthümliches Verhalten der quergestreiften Muskelfaser," SCHULTZE's Archiv, Band v. (1869).

‡ "Beiträge z. Kenntniss d. quergestr. Muskelf.," REICHERT und DU BOIS-REYMOND's Archiv, 1871.

VI. *Appearances under Polarized Light.*

Although at first sight it may seem an easy matter to determine which parts of a muscular fibre are singly and which doubly refracting, yet, in fact (owing no doubt principally to the complex optical conditions which are produced by the heterogeneity of the structures through which the light has to pass), there is hardly any subject in histology in which greater difficulty occurs in arriving at a correct result. Accordingly scarcely any two observers who have carefully investigated living muscular fibre with this object have arrived at precisely the same conclusion. One of the chief difficulties is that of obtaining the muscular fibres in a sufficiently isolated state; for the addition of any fluid is quite inadmissible, and without such addition isolation of the individual fibres is liable to be accompanied by desiccation and loss of the normal structural appearances. Of course the presence of other fibres under or over the particular one we are examining may considerably complicate our observations.

Having fully experienced the difficulties of this part of the investigation, I have taken all the more pains to arrive at a trustworthy result, and therefore feel the less diffidence in stating my own conclusions, although they differ materially from those of other observers, with the partial exception perhaps of Heppner.

The method adopted has been to make the preparation upon a cover-glass, and to enclose it in a moist chamber in the manner already explained. In this way all possibility of pressure is avoided, and fibres are frequently obtained partially isolated from the rest and perfectly living and contractile. For the purpose of illumination, the oxycalcium light has been employed. For observing the optical conditions, as well as other phenomena, of contracting muscle, I have found it a good plan to pass into the moist chamber (whilst a fibre is under observation) air containing a trace of alcohol vapour. Hartnack's polarization-apparatus was used throughout.

The opinion, then, that I have been led to form, by a careful comparison of the appearances presented by muscular fibres in the states respectively of rest and of contraction, when placed between crossed Nicols, and with their axes at an angle of about 45° with the principal plane of either prism, may be shortly stated as follows:—Leaving out of consideration the sarcolemma, nuclei, &c., *the whole of the proper substance of a muscular fibre is anisotropous, with the exception of the* structures here designated *muscle-rods, which are isotropous.*

If we observe under the above conditions a living muscular fibre in the state of rest, the whole fibre appears illuminated on the dark field; and in consequence of this illumination we are able to make out the structural points (such, for example, as the presence of muscle-rods) almost as well as when it is illuminated by ordinary light. The rods are clearly distinguishable as dim streaks on the bright ground of the fibre, the heads giving the appearance, by their contiguity, of a single or double dark dotted line. It may be objected that if the rods were isotropous they would stand out as *black* markings on the bright ground: but this does not necessarily follow; for since they are surrounded by, and imbedded in, the anisotropous substance, any rays which reach them from the lower prism must of necessity pass through this substance, and thus be made available for illumination.

In the contracted fibre the conditions are different; for in this case the heads of the isotropous rods are enlarged and in close contiguity, so that there is no perceptible amount of anisotropous ground-substance between them; and this being the case throughout the thickness of the fibre, we get a composite disk of isotropous substance produced, which remains dark between crossed Nicols. On the other hand, the anisotropous substance has now become collected between the shafts of the rods, disks of anisotropous substance being thus formed, which alternate and nearly correspond in size with those of isotropous. Consequently we have the effect produced of a series of illuminated stripes with dark intervals. The isotropous shafts of the muscle-rods, which are present in the former, do not stand out as dark streaks, for the same reason as that just stated in the consideration of the muscular fibre in the state of rest.

HEPPNER* has given a somewhat similar account to that here given of the appearance of muscle under polarized light. He describes a muscular fibre as consisting of only two substances, which he terms respectively *Hauptsubstanz* and *Zwischensubstanz*, which are disposed in alternating disks. Those of the latter substance he considers to be represented by the dark granular line in the centre of the bright bands; all the rest is *Hauptsubstanz*. The latter, according to him, is anisotropous, the former isotropous. Since the granular line referred to obviously corresponds with the line formed by the contiguous heads of the muscle-rods, it will be seen that HEPPNER'S account, so far as the mere description goes, very nearly agrees with that given by me.

An entire corroboration of the statements above given of the appearance of resting muscle under polarized light has turned up quite unexpectedly in a paper by Dr. F. MERKEL†, which has unfortunately only been in my hands a day or two, in which he makes the following statement (p. 294):—

"In a muscular fibre at rest, viewed under crossed Nicols, the contractile substance and the terminal disks appear bright and clear; the intermediate substance on the other hand so delicately (*exquisit*) singly refracting, that, when the field is completely darkened, there is no trace of it to be seen: the doubly refracting parts lie apparently immediately in contact with one another."

Putting aside MERKEL'S peculiar nomenclature of the parts which, according to his view, compose the substance of the muscle, it is clear that the appearance seen by him indicates that the whole fibre remains bright under crossed Nicols.

Further, I may adduce statements of Prof. BRÜCKE, whose well-known views as to the effect of muscular fibres upon polarized light are entirely different from those here advocated, in support of the accuracy of the description I have given as to the whole of the muscular fibre in a state of rest appearing doubly refracting. **Brücke** states, in effect, that, in the muscles of water-beetles in the living contractile state, he has but rarely been able to convince himself of the existence of an isotropous substance, that it never is so clearly seen as in dead muscle, but even here may be missed altogether. Very often so little isotropous substance appears as to be only represented in the resting muscle by a row of points, which form coherent stripes only during contraction. **Brücke** remarks that this condition is probably the normal one during life, since he has most frequently come across it in perfectly fresh living muscle[*]. It is not difficult to identify **Brücke**'s isotropous substance, which he also terms *Zwischensubstanz*, with the heads of the isotropous muscle-rods above described. But it may be asked, How comes it that in dead muscular fibres, especially if they have been placed in alcohol and subsequently mounted in Canada balsam or dammar-varnish, even though apparently fully extended, we so often observe broad alternating stripes of anisotropous and isotropous substance? To this I would answer that, although these fibres are not actually shortened, yet the elements composing them have tended to assume the condition that ordinarily accompanies contraction of the fibre (see below). And this opinion is fully confirmed by **Brücke**'s statement[†], that the isotropous disks are always broadest in such fibres as have been prevented from shortening at the time of death. It is, in fact, as if we took a fibre that had become fixed at death in the contracted state and mechanically stretched it out to its original length; in which case we may readily conceive the anisotropous and isotropous disks which are present in that state of the fibre to be equally stretched out.

---

* *Loc. cit.*

† "Der Contractionsvorgang im polarisirten Licht," SCHULTZE'S Archiv, Band ix. (Jan. 1873).

And here I am tempted to offer a conjecture respecting the probable changes which take place during the contraction of muscle in the disposition of the structures which I have endeavoured to describe.

It is conceivable that the anisotropous ground-substance is the true contractile part of the fibre, and that it is allied in nature to ordinary protoplasm, but without the granular character commonly met with in the latter[‡]. The muscle-rods may be imagined to be composed of a labile, and at the same time elastic substance of semifluid consistence, possessed of considerable refracting power on light, and in all probability devoid of vital contractility.

---

[*] "Untersuchungen über den Bau der Muskelfasern mit Hülfe des polarisirten Lichtes," Wiener Denkschriften, xv. p. 79.

[†] *Loc. cit.* p. 80.

[‡] Since the above was written my attention has been drawn to a paper by M. **Schultze** (**Reich.** und **Du Bois-Reymond**'s Archiv, 1861), in which that author gives it as his opinion that the substance between the rod-shaped sarcous elements is the remains of the unaltered protoplasm of the embryonal muscle-cell. He would appear, however, to ascribe to it rather a nutrient than a contractile function, still looking upon these as the active elements of the fibre.

When a portion of muscle is called into activity, the contractile substance, or at least that portion of it which is between the *shafts* of the rods, shortens in the direction of the axis of the fibre, swelling out correspondingly in the lateral direction; the rods consequently become compressed in the centre, so that the substance of which they are composed tends to accumulate towards the ends. But these become also enlarged in another way; for the effect of the shortening of the fibre would be, first to press the heads of those in adjacent series against one another, and then, by a continuation of this process, to force them down upon their own shafts, encroaching upon the substance of these and becoming larger at their expense. The change of form may be most aptly compared to that which happens when the end of a thread of glass is put into a flame, the glass as it softens running up into a spheroid.

When the contraction ceases all the processes are reversed: it is possible that elasticity of the muscle-rods is an agent in restoring the fibre to its original length.

To recapitulate:—The general result of my investigations upon muscular fibre in the living state has been to induce me to regard the less strongly refracting intermediate substance which pervades the whole fibre as the contractile, irritable, and consequently essential part of the muscle, whereas the more refracting substance (which, as a rule, in the leg-muscles of *Dytiscus* appears in the form of distinct rod-shaped particles regularly arranged, but unconnected with one another) is, I think, to be regarded as performing a passive function only, and consequently as unessential to the idea of a muscular fibre, so far as its function of contractility is concerned. It is possible that this substance is analogous to that of which the granules ordinarily found in protoplasm are composed, being, however, in the case of striped muscle, for some reason at present unknown to us, arranged in a definite manner. That the ground-substance of muscle is doubly refracting, whereas ordinary protoplasm, such as that of which the pale corpuscles of the blood are composed, is not, cannot be taken as a proof of dissimilarity in nature; for, as is well known, the substance of which the cells of plain muscular fibre is made up (the protoplasmic nature of which few, I imagine, would be prepared to deny) is also doubly refracting. And since, according to the view here adopted, the more refracting substance is to be regarded as the non-essential part of the fibre, we must not be surprised if differences occur in the mode of its arrangement in the muscles of different animals, or even in different muscles of the same animal. In other words, it does not seem imperative that a typical structure should be selected to which all striped muscles must necessarily exactly conform; but, on the contrary, differences in the arrangement of the non-essential elements may, and undoubtedly do, occur without corresponding differences in the essential functional activity of the fibres.

* * *

A great deal has been written within the last few years with regard to the structure of striped muscular fibre. Previously to 1868 the views of BOWMAN, as modified by ROLLETT, were very generally accepted as affording an explanation of most of the appearances observed; some histologists, however, *e. g.* KÖLLIKER, were disposed to regard fibrils extending from one end of the fibre to the other as the ultimate elements of the muscle. In the year mentioned, KRAUSE, in a paper on the subject*, drew particular attention to the transverse line in the centre of the bright band, and, looking upon this as the optical section of a fine membrane stretched transversely across the fibre, described the latter as being divided into a number of flat compartments (*Muskelfächer*), each containing a disk of solid substance in the centre, separated from the membrane above and below by fluid. At the same time, taking the fine lines bounding the polygonal areas described by COHNHEIM in transverse sections to be the optical section of similar membranes running parallel with the axis of the fibre, and of course meeting the others perpendicularly, he described the flat compartments as thus subdivided into a number of muscle-boxes (*Muskelkästchen*), each of them bounded by membranes both at the ends (bases) and sides, each base-membrane being common to two contiguous muscle-boxes. Each muscle-box, he considered, is almost filled by a portion of the dim substance (muscle-prism), this being separated from the base-membranes by fluid. Subsequently KRAUSE described the muscle-prisms as consisting each of a bundle of more minute particles, which he termed muscle-rods (*Muskelstäbchen*). [The transverse line bisecting the clear stripe was known long previously to KRAUSE'S paper on the subject. It was described by BUSK and HUXLEY† as occurring in the muscles of insects; and since they observed with marvellous correctness that it was not so much a continuous line as a succession of contiguous dots, it was supposed by them to be due to the existence of a row of minute sarcous elements interpolated between the rows of larger ones, which were regarded as forming the darker stripes of the fibre. The rod-like character of the so-called sarcous elements had also been long known: it was distinctly figured by BRÜCKE; and SHARPEY had more lately drawn attention to the close connexion which exists between these rod-shaped particles and the minute dots composing the transverse line, only just falling short of tracing the one into the other—this, too, both in the muscles of insects and in human muscle‡.] HENSEN §, writing about the same time as KRAUSE, gave a somewhat similar account of the structure of muscle, also drawing especial attention to the apparent membrane bisecting the light stripe; as regards some points, however, his account was entirely at variance with that given by KRAUSE.

The next contribution to the subject of any importance was that of HEPPNER‖, who employed the still living contractile fibres of *Hydrophilus piceus.* He assumed the dark transverse line in the middle of the clear stripe to represent a *continuous disk* composed of a substance (*Zwischensubstanz*) possessing a *lower* index of refraction than the rest of the fibre, and endeavoured to show, by the assistance of a diagram, that the bright appearance on each side of it is produced by a total reflection of the rays of light from its surfaces—considering, from the fact of its similar behaviour under crossed Nicols, the substance forming the clear stripe to be similar in nature to the rest of the muscle-substance, with the exception of the *Zwischensubstanz* before mentioned. As a further indication that the bright bands are due to such an optical effect as he described, HEPPNER remarked that their position became altered according as the mirror was inclined or the stage rotated.

---

* "Ueber den Bau der quergestreiften Muskelfaser," Zeitschr. f. rat. Med. xxiii.

† KÖLLIKER'S 'Manual of Human Histology.' Sydenham Society's Translation, 1853.

‡ QUAIN'S 'Anatomy,' 7th ed. 1867, vol. i. p. cxix.

§ Arbeiten aus dem Kieler physiologischen Institut, 1868.

‖ "Ueber ein eigenthümliches optisches Verhalten der quergestreiften Muskelfaser," SCHULTZE'S Archiv, v. 1869.

Quite recently three important contributions to the study of the structure of striped muscular fibre have appeared; those, namely, by FLÖGEL*, MERKEL†, and ENGELMANN‡ respectively. MERKEL, studying the fibres of the Arthropoda, principally by means of alcohol preparations, finds the transverse line of KRAUSE to be not simple, as believed by the latter, but in reality to be made up of two lines representing juxtaposed membranes (terminal disks or *Endscheiben*), best seen when the fibre is stretched. He further describes an exceedingly indistinct disk (*Mittelscheibe*) in the middle of the dim stripe of the muscle, not always visible, and often only represented by a somewhat lighter appearance of that stripe at this part. The contractile substance of the muscle he describes as being, in the state of rest, arranged on either side of this median disk, with a clear fluid separating it from the terminal disks above and below. The enclosure of each muscle-element is completed at the sides by a lateral membrane. In contraction of the muscle MERKEL describes the contractile substance as at first becoming diffused throughout the muscle-element, and finally becoming collected in the vicinity of the terminal disks. By what mechanism such locomotion is capable of producing shortening of the muscle is not explained§.

FLÖGEL, who for the most part employed muscle of *Trombidium* which had been treated with osmic acid, describes a fibre as divided into compartments, similar to those described by KRAUSE, by means of transverse partitions (*Querwände*), which, however, he believes to be formed by the juxtaposition of granules interpolated at regular intervals in the course of the fibrils, which latter extend from end to end of the fibre, imbedded in a ground-substance which is probably of a fluid nature. In the median portion of each muscle-compartment these fibrils, if I understand FLÖGEL's meaning aright, are more marked (*Säulen*) than near the transverse partitions, in the immediate neighbourhood of which the substance is clear and homogeneous, but contains both above and below each transverse partition a row of minute granules (granule-layer); and since it may sometimes be seen that each granule lies in the same longitudinal line as one of the minute columns in the central part, the two are probably parts of the same fibril.

---

* "Ueber die quergestr. Muskeln der Milben," SCHULTZE's Archiv, viii. Nov. 1871.

† "Der quergestreifte Muskel," SCHULTZE's Archiv, viii. Jan. 1872.

‡ "Mikroskop. Untersuchungen über die quergestr. Muskelsubstanz," PFLÜGER's Archiv, vii. Jan. 1873.

§ It is but fair to add that MERKEL's results are principally based upon observations on the so-called fibrils of the thorax of insects; and these present in many respects a structure entirely different from that met with in the muscles of the legs, this apparent difference being due to a different arrangement of the non-essential substance (compare p. 438).

A view of muscular structure still more complicated has very lately been set forth by ENGELMANN in his exceedingly elaborate article on the subject. ENGELMANN enumerates no less than ten distinct layers as included in each muscle-segment or compartment (*Muskelfach* of KRAUSE). Each of the segments, according to him, is bounded at each end by a thin but well-marked layer (*Zwischenscheibe*), often appearing granular, and which is common to two contiguous segments. This corresponds with the transverse partition of FLÖGEL. Passing inwards from these we come first upon a clear layer, then a somewhat dark layer (*Nebenscheibe*), which often appears to consist of a row of granules (the granule-layer of FLÖGEL), then upon another clear layer, and finally, in the centre of the muscle-compartment, a broad dim layer (*Querscheibe*), the middle portion of which appears somewhat less dim than the rest (*Mittelscheibe*). Each of these layers is described with great minuteness by ENGELMANN. He does not, however, maintain that they are all to be made out in every case, but only in those instances in which a considerable interval separates the stripes. He further asserts that the *transverse* markings are the only ones which are met with in the living fibre in its normal condition; and in proof of this he states that the transverse disks appear completely homogeneous when viewed *in situ* in the living animal (as, for instance, in minute transparent Crustacea), exhibiting, therefore, no trace of longitudinal striation. The pallisade-like arrangement of the elements which has been described is, he maintains, due to a change which occurs at the moment of death of the fibre, those portions of a fibre in which individual rods have become visible being, according to him, no longer irritable. To explain these so frequent appearances, ENGELMANN assumes the muscular substance to be wholly composed of closely compressed, elongate, prismatic elements extending the whole length of the fibre, and exhibiting at regular intervals differences in chemical and physical properties, producing thus the several transverse layers. He conceives that at the moment of death of the fibre a coagulation and shrinking of these elements take place, accompanied by expression of fluid; and in this way accounts for the fibrillar and granular character which the transverse disks commonly exhibit.

Of the accounts given by the various authors with regard to the behaviour of muscle under polarized light, I have thought it best to say nothing in this place—partly on account of the irreconcilable differences of opinion on the subject, partly because the question has already been very fully discussed in a preceding page.

It only remains for me briefly to point out the parts which, in the several accounts here quoted, seem to correspond with those enumerated by me in describing the appearance of the living muscle of *Dytiscus*. But, first, I would take the opportunity of expressing my unqualified dissent from the positive assertions of ENGELMANN, above noticed, with regard to the homogeneous appearance of muscular fibre in the living state, at all events so far as *Dytiscus*-muscle is concerned. I would affirm, on the contrary, that *however quickly* the preparation is made (and the quicker the better), we find numerous muscular fibres exhibiting the structure I have described, in which the muscle-rods appear with perfect distinctness throughout the whole extent of the fibre, and that such fibres are capable of repeatedly undergoing the most complete spontaneous contraction: indeed after the death of the fibre the distinctness of the picture becomes always very much impaired, and often the structural appearances become entirely obliterated. Further, I may remark that since reading ENGELMANN's article I have taken what opportunities offered of examining the muscles of minute aquatic Crustacea and insects whilst still in the living body, and as a result of such examination may state that, in spite of the difficulties to observation offered by the presence of the chitinous integument and the small size of the muscular elements, there is no great difficulty, with a good immersion-glass, in seeing that they possess an apparent longitudinal fibrillation. If further proof were needed, it is to be found in an exceedingly interesting paper by Professor WAGENER*, in which the appearances observable in the muscles of the *Corethra*-larva in the living state are fully detailed. But to return to our subject.

The transverse membrane of KRAUSE and the narrow disk of intermediate substance (*Zwischensubstanz*) of HEPPNER would seem to be referable to the heads of two contiguous series of muscle-rods, which, as before stated, often meet in the middle of the clear stripe. The terminal disks of MERKEL, the granule-layers of FLÖGEL, and the *Nebenscheiben* of ENGELMANN are also, I think, to be referred to the same structures, which are by these observers correctly differentiated into two rows. The *Stäbchen* of KRAUSE and ENGELMANN and the *Säulen* of FLÖGEL would appear to correspond with the shafts of the muscle-rods of my description. There remain the *Mittelscheibe* of MERKEL and others, and the line between each two muscle-series, which is to be seen only in very extended conditions of the fibre (*Querwand*, FLÖGEL; *Zwischenscheibe*, ENGELMANN). To explain these appearances, it is necessary to revert to what has been said with regard to the minute oil-globules in the experiment before mentioned†. It was there noted that the bright halo around each oil-globule is often seen to be bounded by a marginal line rather darker than the rest of the field, and probably to be explained by interference. The granules in muscle (rod-heads) must each have a similar effect upon the light; and since they are disposed in rows, so that their bright haloes coalesce into bright bands, these darker margins must similarly coalesce into dim bands. Consequently the edges of the broad dim stripe (*Querscheibe*, Plate XXXIII. fig. 1, *a*) of muscle will be caused to appear somewhat darker‡ than the central part (*e*), which latter has been for this reason taken for a distinct layer (*Mittelscheibe*). Of course in the case of a muscular fibre all these effects are very much more marked than if we had to deal with a single series of granules, since other rows which are somewhat out of focus contribute to increase the result §.

---

* "Ueber einige Erscheinungen an den Muskeln lebender Thiere," Sitzungsb. d. Gesellsch. z. Beförderung der gesammten Naturwissenschaften zu Marburg, No. 8, August 1872.

† See footnote, page 434.

‡ The contrast with the bright band would probably tend to enhance this effect.

§ When a very strong light is employed coloured fringes are often visible on the confines of the dim and clear stripes, and doubtless result from such interference effects as I have indicated.

The *Querwand* or *Zwischenscheibe* may probably be similarly explained; for where it appears the rows of rod-heads of adjacent series are so drawn away from one another by the extension of the fibre that their bright borders are no longer blended, and a dim line (in all probability rendered darker by interference) comes into view between them. The argument in favour of the existence of a continuous membrane across the fibre, drawn from the fact that indentations of the sarcolemma pretty constantly occur at this place, loses its weight when we reflect upon the extreme delicacy of the sarcolemma, and the necessity which must exist for it to follow any changes of shape which may occur in the enclosed substance.

Description of the Plate.

PLATE XXXIII.

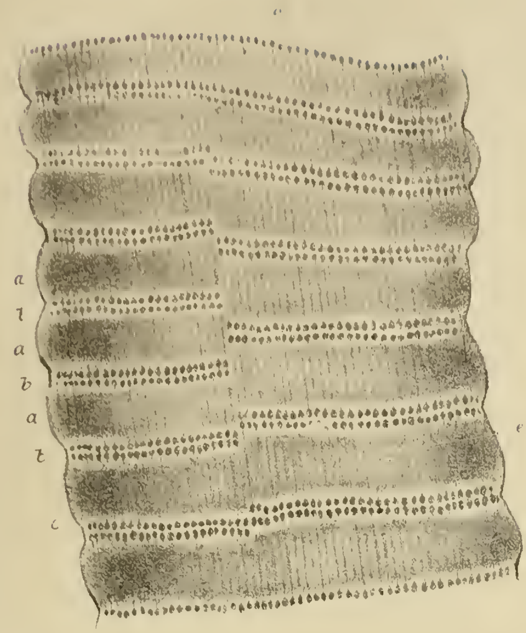
Fig. 1. Portion of a muscular fibre of *Dytiscus* in the state of rest.
  a a a. Dim stripes.
  b b b. Bright stripes.
  c. Double dotted line in bright stripe formed by the heads of
  d. The muscle-rods.

Fig. 2. Muscular fibre undergoing contraction.
  R R. Portions still at rest.
  P P. Contraction proceeding.
  C. Contracted portion.
  $a\ a_{\prime}$. Dim stripes.
  $b\ b_{\prime}\ b_{\prime\prime}$. Bright stripes.
  $c\ c_{\prime}\ c_{\prime\prime}$. Lines formed by rod-heads.

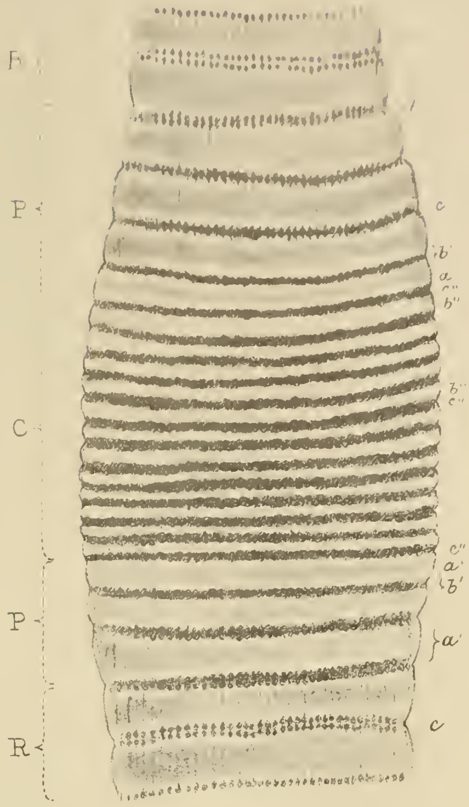
Fig. 3. Transverse section of muscular fibre of *Dytiscus*. The irregular patch in the centre, containing a round nucleus, is the so-called central protoplasm.

Fig. 4. Transverse section of muscular fibre of Water-beetle, made whilst frozen, showing the appearance of radiating lines described in the text.

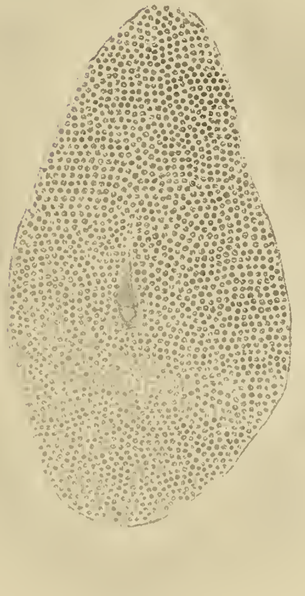
1



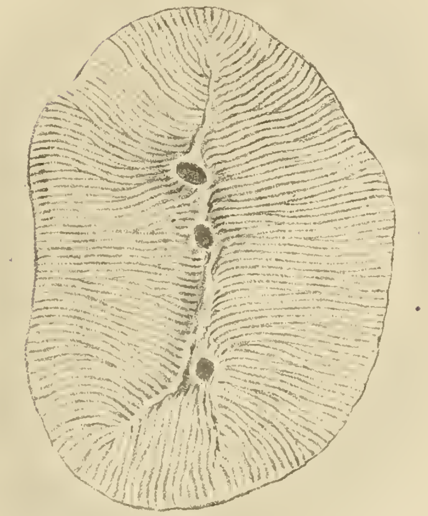
2



3



4



T Wesley

W West & Co.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

XIII. *Results of the Comparisons of the Standards of Length of England, Austria, Spain, United States, Cape of Good Hope, and of a second Russian Standard, made at the Ordnance Survey Office, Southampton. By Lieutenant-Colonel* A. R. CLARKE, *C.B., R.E., F.R.S., &c., under the direction of Major-General Sir* HENRY JAMES, *R.E., F.R.S., &c., Director-General of the Ordnance Survey. With a Preface and Notes on the Greek and Egyptian Measures of Length by Sir* HENRY JAMES.

Received May 21,—Read June 19, 1873.

THE following account of the results of the Comparisons of the Standards of Length of England, Austria, Spain, United States, Cape of Good Hope, and of a second Russian Standard at the Ordnance Survey Office has been drawn up by Lieutenant-Colonel CLARKE, and is a sequel to the abstract of the results of the Comparisons of the Standards of Length of England, France, Belgium, Prussia, Russia, India, and Australia which the Royal Society has done us the honour to publish in the Philosophical Transactions for 1867, vol. clvii. p. 161.

The accurate determination of the lengths of the various standards employed by so many nations in the measure of the bases of their triangulations, which are now being united into one vast network of triangles, covering the whole of Europe, can scarcely fail to be of great importance for the advancement of physical science. To the comparison of these lengths I have added the result of our endeavours to recover the correct lengths of the most ancient measures of length with which we are acquainted, viz. those of Ancient Egypt, not only because our own measures are obviously derived from them, but also because we thus obtain the accurate relative value of the measures and distances given in the most ancient works on Astronomy and Geodesy which have come down to us.

The Ancient Egyptians employed two measures of length, viz. the common and the royal cubits.

1st. As regards the *common cubit*, we have the statement of HERODOTUS that the Egyptian cubit was equal to the Greek cubit, "that of Samos;" and we learn from the measurements of the Hecatompedon at Athens, by Mr. PENROSE, that the Greek foot was equal to 1·013 foot, or 12·156 inches, and consequently the Greek cubit was equal to 1·520 foot, or 18·240 inches.

2nd. The most recent measures of the base of the First or Great Pyramid, that of King CHEOPS, viz. those made by the Royal Engineers and Mr. INGLIS, a civil engineer, give a mean length of 9120 inches, or 500 cubits of 18·240 inches for the side of the square base, or 750 Egyptian feet, each Egyptian foot being equal to 1·013 English foot.

3rd. The Second Pyramid, according to the measures of Colonel Howard Vyse and Mr. Perring, has a base of 707·5 feet square, or 700×1·011 feet.

4th. The Third Pyramid has a base, according to Vyse and Perring, of 354·5 feet, or 350 Egyptian feet square, of 1·013 English foot exactly.

We may therefore confidently assume that 1·013 foot was the true length both of the ancient Greek and the ancient common Egyptian foot, and that the length of the *common Egyptian cubit* was 18·240 inches.

We have in the British Museum a double *royal cubit*, found in the ruins of the Temple of Karnak in Egypt; and I found its length to be 41·40 inches, and that of the single cubit consequently 20·70 inches, or 1·725 foot.

The pyramid which stands in the middle of the three, before the Great Pyramid (that of the daughter of King Cheops), has a base, according to Vyse and Perring, of 172·5 feet square, and therefore 100 royal cubits square exactly.

But the same authors give the breadths of no less than seven of the passages in the pyramids, including the entrances to the First, Second, and Third Pyramids, all of 41·5 inches (two cubits of 20·750 inches).

Dourstier, from the measures of the nilometer at Elephantine and of three or four cubits found in the ruins of Memphis, which almost exactly correspond with each other, estimated the length of the royal cubit at 20·721 inches (see Condée, 'Dictionnaire des Poids et Mesures').

Looking to these facts, and feeling it almost certain that the common and the royal cubit had some definite relation to one another, like that between the link and foot of our own country (66 feet equal 100 links), I infer that the most probable length of the *royal cubit* was 20·727 inches, and that 88 *royal cubits* were equal to 100 *common cubits* of 18·240 inches.

This does not admit of rigid demonstration. The dimensions of Vyse and Perring seem to be given to the nearest half inch, and the measures of length sold in this country differ from one another as much as the length of the double cubit in the British Museum differs from its estimated length.

Henry James, *Major-General.*

[Note.—Since writing the above I have had an opportunity of consulting Don V. Vazquez Queipo's 'Essai sur les Systèmes Métriques &c.,' in which he gives a description of ten royal cubits which have been found from time to time in the ancient buildings of Egypt. He has numbered these from 1 to 10, and given the lengths of four of them, and the mean length of all the Standards found.

		m.		inches.
No. 5.	Stone	=0·52650	or	20·728
8.	Wood	=0·52514	„	20·675
9.		=0·52598	„	20·708
10.		=0·52448	„	20·649
Mean length of all the Standards		=0·52500	„	20·669

No. 10 is the royal cubit from the Temple at Karnak, which is in the British Museum, and which I measured, and found to be of the same length as is here given of No. 9. No. 10 is made of wood, as are also Nos. 8 & 9. But No. 5, now in Florence, is made of slate or schist, and a much higher value must be attached to its length than to the lengths of the three wooden ones, because, being of stone, it was not liable to alteration, as those made of wood were, during the 3500 years, at least, which must have elapsed since they were made.

We cannot suppose for a moment that stone cubits were used by the artificers employed in building the ancient temples; the workmen were supplied with the wooden double cubits, of which Nos. 9 & 10 are examples.

These wooden cubits are divided, although apparently with a fine saw, with as much, or even greater accuracy than the generality of the measures with which the workmen of the present day are supplied.

The stone cubits were probably preserved as standards, with the name of the reigning King engraved upon them, and referred to to verify the lengths on the wooden cubits.

The length of this stone, royal cubit, $0^{m}\cdot5265$ or 20·728 inches, corresponds with my previously estimated length, $0\cdot52646=20\cdot727$; and the length of the common cubit is $0\cdot46329=18\cdot240$.

The royal cubit is divided into 7 palms of 2·961 inches, the common cubit into 6 palms of 3·040 inches; and the mean is exactly 3 inches: the length of the English foot is consequently equal to the mean length of the ancient Egyptian common and royal foot, although it probably is so by accident only.—H. J., August 1873.]

Comparison Apparatus.

The Comparisons of Standards to be recorded in the present paper have been made in the same room, and with generally the same apparatus, as those described in a previous paper read before the Royal Society, December 13, 1866. In that paper were given the results of the Comparisons of the Standards of England, France, Belgium, Prussia, Russia, India, and Australia; in the present paper the results will be given for the Standards of Austria, Spain, America, the Cape of Good Hope, and a second Russian Standard.

The general method of conducting the comparisons explained in the former paper has been adhered to with no material alterations. No kind of unsteadiness in the piers carrying the microscopes has at any time been noticed, nor in the mahogany beam carrying the bars under observation. The insulation of the flooring has remained perfect.

Some little improvements, however, have been made. The candles were originally held in wooden conical holders, which rested immediately upon the cast-iron plates holding the microscopes. In moving the candle-holder, so as to keep the centre of the image of the flame on the dot, it seemed possible that a disturbance might be communicated to the cast-iron microscope-holders. In order to remove this possibility a new form of candle-holder was introduced, which does not come into contact with the cast-iron plates, and admits of being very easily adjusted to the proper position from time to time. Some improvement has been also made in the apparatus for measuring calibration errors of thermometers, and also (mainly by increasing the quantity of water) in that for comparisons of thermometers.

The values of one micrometer-division of the microscopes H and K obtained in 1863 were

$$h=0{\cdot}79494\pm0{\cdot}00008,$$

$$k=0{\cdot}79800\pm0{\cdot}00009;$$

in 1865,

$$h=0{\cdot}79566\pm0{\cdot}00008,$$

$$k=0{\cdot}79867\pm0{\cdot}00009.$$

In 1869 the values were determined again with the result,

$$h=0{\cdot}79564\pm0{\cdot}00010,$$

$$k=0{\cdot}79837\pm0{\cdot}00010.$$

Two new micrometer-microscopes marked I and J have been added to the apparatus. They are longer than H and K; the distance from the object observed to the object-glass is 4 inches, from the object-glass to the micrometer-threads 14·6 inches. The value of one division of either of these microscopes is very little different from that of one division in the microscopes H and K. They were determined from ten measurements of the same space, giving it equal to $1368{\cdot}45i$ or $1381{\cdot}50j$, where i and j represent the values of one division in the respective microscopes. From these measures we get

$$i=0{\cdot}81032\pm0{\cdot}00018,$$

$$j=0{\cdot}80270\pm0{\cdot}00015.$$

These microscopes have never been used for any large measurements, and the values are therefore sufficiently precise.

The space between the lines on the contact-apparatus has been repeatedly examined, and appears to be as nearly as possible invariable. The results obtained from very numerous comparisons in different years are:—

In 1863 . . . . $\delta=565{\cdot}62$,
„ 1864 . . . . $\delta=565{\cdot}55$,
„ 1865 . . . . $\delta=565{\cdot}69$,
„ 1869 . . . . $\delta=565{\cdot}64$.

The Klafter.

Two copies of the Vienna Klafter have been compared at Southampton, viz. the Pulkowa copy and the Milan copy. In order to effect the measurement of the klafter, it was most convenient to construct, in the first instance, a bar of the length of half a klafter, to determine its length by comparison with the standard yard and standard foot, and then to compare the klafters with two lengths of this bar.

The half klafter was constructed by Messrs. TROUGHTON and SIMS; it is of Swedish iron 38·3 inches in length, 1·0 in breadth, and 0·475 inch in depth. On its upper surface it bears four raised disks, marked a, b, c, d; the distance $a\,b = 1{\cdot}33$ inch, $b\,c = 4{\cdot}00$ inches, and $b\,d = 36$ inches; thus the distance between the transverse lines on a and d, marking the total length of the half klafter, is 37·33 inches approximately. The necessity for the line c arises from the circumstance that the small space $a\,b$ could not be compared with a corresponding space on the standard foot, as two micrometer-microscopes cannot be fitted up at so small a distance apart; consequently $a\,b$ is determined as the difference between the spaces $a\,c = 5{\cdot}33$ inches and $b\,c = 4{\cdot}00$, which two spaces were compared with corresponding spaces on the standard foot. We shall designate this bar by the symbol $K_{\frac{1}{2}}$.

For convenience, and to save reference to the former paper, it may be well to explain that the standard foot has on its upper surface thirteen division-lines marked a, b, c, d, e, f, g, h, k, l, m, n, p, marking the twelve inches. The first inch $(a\,b)$ is subdivided into tenths by lines marked (from a towards b) 1, 2, 3, 4, 5, 6, 7, 8, 9. The tenths $[2\,.\,3]$ and $[6\,.\,7]$ are subdivided again into tenths. In the former of these spaces falls the toise-line τ, and in the second the metre-line μ. The line by which the length of the half klafter is determined also falls in $[6\,.\,7]$; it is the seventh line from 6 towards 7, or the third line from 7 towards 6. The error of this line with reference to the lines 6 and 7 is, the unit being the one millionth of a yard,

$$x_k = -4{\cdot}29 \pm 0{\cdot}085\,;$$

that is to say, if $[6\,.\,k]$ be the distance from the line 6 to the line k,

$$[6\,.\,k] = \tfrac{7}{10}[6\,.\,7] + x_k.$$

The space $[a\,c]$ of the half klafter was compared with the space $[k\,g]$ on the standard foot. We therefore require to have the probable error of $[k\,g]$. Now $[k\,g] = [a\,g] - [a\,k]$; and expressed in terms of the errors of the other lines the value of $[k\,g]$ is

$$[k\,g] = \frac{533}{100}\mathrm{I} - \frac{3x_6}{10} - x_k - \frac{7x_7}{10} - \frac{67x_b}{100} + \frac{533x_g}{600},$$

where $x_6\,x_7$ are the errors of the lines $6\,.\,7$ with respect to the lines $a\,b$, and $x_b\,x_g$ the errors of the lines $b\,g$ with respect to the lines $a\,p$. Also $\mathrm{I} = \tfrac{1}{12}$ of the standard foot F, From this expression we can at once determine the probable error of $[k\,g]$; we shall not enter into the details of the calculation, but simply give the result, namely,

$$[k\,g] = \tfrac{533}{100}\mathrm{I} + 1{\cdot}40 \pm 0{\cdot}108.$$

This is on the supposition of the klafter and the yard being both at the temperature of 62°.

The standard temperature of the Vienna klafter is 61°·25 Fahrenheit, or 16°·25 Centigrade, and this temperature is therefore adopted for the half klafter; consequently we require the length of [*k g*] at the same temperature. Now the comparisons made between the standard foot and the standard yard Y_{55} give this result,

$$F=\tfrac{1}{3}Y_{55}-0{\cdot}36\pm0{\cdot}104,$$

the foot and yard being both at 61°·25. Hence, at the same temperature,

$$[k\,g]=\tfrac{533}{3600}Y_{55}+1{\cdot}24\pm0{\cdot}118.$$

The space [*b c*] of 4 inches on the half klafter was compared with the space [*c g*] of 4 inches on the standard foot. The value of this space is, both the foot and the yard being at 61°·25,

$$[c\,g]=\tfrac{4}{36}Y_{55}-2{\cdot}73\pm0{\cdot}062.$$

The space [*b d*] of 36 inches was compared with the standard yard Y_{55} twenty times between March 19th and 27th, 1866, at temperatures varying from 41°·6 to 43°·7—sixteen times between June 25th and July 2nd, the temperature varying from 62°·7 to 67°·4—and six times in September 1867, at about 64°,—in all forty-two comparisons.

Reduced by the method of least squares the result is

$$[b\,d]=Y_{55}+0{\cdot}17+(t-61^\circ{\cdot}25)\ {\cdot}0224.$$

The reciprocals of the weights of the determinations of the quantities 0·17 and ·0224 are 0·03204 and 0·00018 respectively; and the sum of the squares of the forty-two errors of observation is

$$\Sigma(e^2)=19{\cdot}949.$$

Hence we find the probable error of a single comparison to be

$$\pm0{\cdot}674\sqrt{\frac{19{\cdot}949}{42-2}}=\pm0{\cdot}476.$$

The probable error therefore of 0·17 is

$$\pm0{\cdot}476\sqrt{{\cdot}03304}=\pm0{\cdot}085;$$

and at the temperature of 61°·25,

$$[b\,d]=Y_{55}+0{\cdot}17\pm0{\cdot}085.$$

The 4-inch space [*b c*] on the half klafter was compared with the space [*c g*] on the foot fifteen times between April 13th and 19th, 1866, at temperatures varying between 47° and 49°—ten times between June 9th and 13th, the temperatures varying from 60° to 62°—and six times in September 1867, at the temperature of 58°.

The 5·33-inch space [*a c*] was compared with the space [*k g*] on the foot ten times in April 1866, at a temperature varying little from 46°—fifteen times in June of the same year, at temperatures varying little from 60°—and five times in September 1867, the temperature being 62° or 63°.

In order to reduce these comparisons, put

$x_{\prime}=[b\,c]-[c\,g]$ . . . . . at 61°·25 Fahr.
$x'=[a\,c]-[k\,g]$ . . . . . ,,
$y_{\prime}=$expansion of 1 inch of half klafter for 1° Fahr.
$y'=$,, ,, foot ,, ,,

Also for convenience put $4(y-y')=3y$; then the equations of condition take the form

$$\begin{aligned}
&x_{\prime}+3a_1y-b_1=0,\\
&x_{\prime}+3a_2y-b_2=0,\\
&\vdots\\
&x'+4a'_1y-b'_1=0,\\
&x'+4a'_2y-b'_2=0,\\
&\vdots
\end{aligned}$$

which give, finally, a system of equations of the form

$$\begin{aligned}
&0=31\,x'+3(a)y-(b),\\
&0=30\,x'+4(a')y-(b'),\\
&0=3(a)x_{\prime}+4(a')x'+\{9(a^2)+16(a'^2)\}y-3(ab)-4(a'b').
\end{aligned}$$

The substitution of the numerical values gives

$x_{\prime}=+4·10$ . . . with reciprocal of weight$=0·04457$,
$x'=-1·86$ . . . ,, ,, $0·04721$,
$y=+0·00043$,, ,, $0·00003$.

The sum of the squares of the residual errors of the sixty-one equations is 11·295; hence the probable error of a single comparison is

$$\pm 0·674\sqrt{\frac{11·295}{61-3}}=\pm 0·297;$$

and the lengths of the two small spaces are therefore, both bars being at the temperature of 61°·25, these:—

$$\begin{aligned}
&[b\,c]=[c\,g]+4·10\pm 0·063,\\
&[a\,c]=[k\,g]-1·86\pm 0·065.
\end{aligned}$$

We now know the values of the different spaces on the half klafter, namely, by the difference of the last two equations,

$$[a\,b]=[k\,c]-5·96,$$

and

$$[b\,d]=\mathrm{Y}_{55}+0·17;$$

adding these together,

$$[a\,d]=\mathrm{Y}_{55}+[k\,c]-5·79.$$

The difference of the expressions we have given for $[k\,g]$ and $[c\,g]$ gives

$$[k\,c]=\tfrac{133}{3600}\,\mathrm{Y}_{55}+3{\cdot}97\,;$$

consequently the length of the half klafter is

$$[a\,d]=\tfrac{3733}{3600}\,\mathrm{Y}_{55}-1{\cdot}82.$$

In order to determine the probable error of this result, it is necessary to form the algebraic expression for $[a\,d]$, which involves all the observations and operations. It is found to be this:—

$$[a\,d]=\tfrac{3733}{3600}\,\mathrm{Y}_{55}+\tfrac{133}{600}\,x_g-\tfrac{67}{100}\,x_b+x_c-\tfrac{3}{10}\,x_6-\tfrac{7}{16}\,x_7-x_k+\tfrac{133}{1200}\,v+x+x'-x_{\prime}.$$

This compound error is formed from seven independent operations. The first term in x_g depends on the subdivision of the standard foot into two 6-inch spaces; the second, involving the terms in x_b and x_c, on the determination of the errors of the different inch lines on one half of the foot; the third, the terms in $x_6\,x_7$, on the division of one of the inches into tenths; the fourth, x_k, on the division of one of the tenths into hundredths; the fifth, in v, on the comparison of the standard foot with the standard yard; the sixth, in x, on the comparison of the standard yard with the half klafter; and the seventh, $x'-x_{\prime}$, on the comparison of the small spaces on the half klafter with the foot. Taking the different component probable errors in this same order, we get the quantity

$$\pm\sqrt{\{(\cdot008)^2+(\cdot045)^2+(\cdot052)^2+(\cdot085)^2+(\cdot011)^2+(\cdot085)^2+(\cdot076)^2\}},$$

which is equal to $\pm 0{\cdot}158$.

The length of Y_{55} at 61°·25 is (see 'Comparisons of Standards,' page 276) 4·886 less than its length at 62°, and at 62° it is less than a true yard by 0·40; hence the length of the half klafter at 61°·25,

$$\mathrm{K}_{\frac{1}{2}}=1{\cdot}03693714\,\mathfrak{Y}\pm{\cdot}00000016,$$

where $\mathfrak{Y}$ is a true yard.

During the comparisons the bar was supported on two knife-edges, at one fourth and three fourths of its length. The positions of these supports are marked on the bar.

The Pulkowa Copy of the Klafter.

This is a bar of steel (apparently) 0·55 inch in breadth and 1·06 inch in depth, but not very evenly planed. On its under surface are fixed small brass pieces at one fourth and three fourths of its length, on which it is supported during comparisons. Its upper surface has seven inlaid plates of silver, on each of which is engraved a dot. The extreme dots are one toise apart. Near one of the end dots is the klafter dot. Two other dots mark the half klafter and the half toise. The two remaining dots subdivide the half klafter into *thirds* or Vienna feet. We shall use the symbol K′ for the length of the klafter on this bar.

The klafter and the half klafter were mounted side by side in a box for comparison, their middle points being opposite one another. The microscopes H and K being mounted at the distance of half a klafter apart, the order of observation at each visit was this:—

1st, the thermometers;
2nd, the half klafter;
3rd, the first half of the Vienna klafter;
4th, the second half of the Vienna klafter;
5th, the half klafter;
6th, the thermometers.

The "first half" of the Vienna klafter is that which is on the same side with the toise dot: we shall denote it by $K'_{1.2}$, and the second half by $K'_{2.3}$; so that $K'_{1.2}+K'_{2.3}=K'$.

The klafter and half klafter were compared twenty times in September 1867, at temperatures varying between 61°·3 and 64°·7, and seven times in January 1868, at temperatures varying between 37° and 38°·6.

The reduction of these comparisons by least squares, putting $x+fy$ and $x'+fy$ for the excess of the first and second halves of the klafter over the half klafter at the temperatures $61^\circ{\cdot}25+f$, leads to a system of equations,

$$0=n(x+x')+2(f)y-(j)-(j'),$$
$$0=(f)(x+x')+2(f^2)y-(fj)-(fj'),$$
$$0=n(x-x')+(j')-(j);$$

and the substitution of the numerical values gives

$$x=+80{\cdot}03,$$
$$x'=+83{\cdot}88,$$
$$y=-\ 0{\cdot}593.$$

If we assumed as true the equation $K'_{1.2}+K'_{2.3}=K'$, we should arrive at the result,

$$K'=2K_{\frac{1}{2}}+163{\cdot}91:$$

but this is not so; for an examination of the alignment of the dots shows that the centre dot is considerably misplaced. In order to measure the quantity, a very fine silk thread was stretched tightly just above the surface and close to the dots. Measurements were then made, and with this result, that the centre dot is 553 micrometer-divisions (one division $=\frac{1}{12400}$ inch) off the line joining the *end dots* of the klafter: it is also very slightly *above* the line joining the end dots; but this deviation is much smaller, and not large enough to produce any error. Now the 553 divisions correspond to about 1240 millionths of a yard. If we write δ for this deviation, it is clear that the distance of the extreme dots is less than the sum of the two portions by

$$\frac{\delta^2}{\frac{1}{2}K'}$$

where K is the length of the klafter—that is to say, a correction of

$$-\frac{1240^2}{1036942}=-1{\cdot}48$$

has to be applied to $x+x'=163{\cdot}91$. We have therefore finally this result, that the Pulkowa klafter exceeds two lengths of the half klafter by 162·44, or

$$K'=2K_{\frac{1}{2}}+162{\cdot}44\pm0{\cdot}38.$$

The Milan Copy of the Klafter.

The Milan copy of the Austrian klafter, which is deposited in the Observatory of Brera, in charge of Dr. SCHIAPARELLI, was, at the instance of Professor CHARLES LITTROW, Director of the Observatory at Vienna, borrowed by the Imperial Academy of Sciences of Vienna from the Italian Government, and sent to Southampton, under charge of Dr. EDMUND WEISS, to be compared with the yard and other standards. We shall denote this bar by the symbol K''. It is a bar of soft Styrian iron, 0·86 inch in breadth and 1·31 in depth. The upper surface has inlaid plates of platinum at its extremities, carrying dots, the distance between them being the klafter. At the left end of the bar is the inscription "K. K. Polytechn. Institut in Wien 1856," and in the centre "Wiener Klafter bei +13° Réaum. (Mass. der Punkte)." The lower surface has three dots, on inlaid platinum plates, marking the klafter and its subdivision into halves. The dots on the upper surface are marked I, II, those on the lower surface are marked 1, 2, 3. The bar is supported on points about one fourth and three fourths of its length; as in the Pulkowa klafter, small brass pieces or feet are screwed to the bar to insure an invariability in the supporting pressures.

The dots on this bar are very large, and this circumstance introduces a considerable amount of discord in the observations. The centre dot 2 is the largest.

Between April 17th and 22nd ten comparisons were made in the same manner as for the Pulkowa klafter, at a temperature of about 50°, and fourteen between July 6th and 12th, the temperature varying from 60°·7 to 62°·5.

The observations being reduced in the same manner as described for the Pulkowa klafter, give

$$K''_{1.2}=K_{\frac{1}{2}}+66{\cdot}73,$$

$$K''_{2.3}=K_{\frac{1}{2}}+72{\cdot}91.$$

Hence, at the temperature of 61°·25, the Milan klafter exceeds two lengths of the Ordnance half klafter by 139·64. The probable error of this determination is

$$\pm0{\cdot}865\sqrt{\cdot4205}=\pm0{\cdot}561.$$

This is a large quantity, and is due, in great measure, to the large size of the dots. The extreme dots 1, 3 on this bar measure about 115 divisions in diameter, and the central dot 2 measures 135 divisions, which is equivalent to 107 millionths of a yard.

Comparison between the Pulkowa and Milan Klafters.

The Milan klafter was compared with the Pulkowa copy in May, June, and July, 1869. Both surfaces of the former were compared—that is, both the distance [1 . 3] and the distance [I . II]. The klafter distance [1 . 3] was compared with the Pulkowa klafter ten times between May 3rd and 6th, at a temperature of about 53°—five times on June 12th and 14th, at about 58°—and five times on July 3rd and 5th, at near 60°.

The distance [I . II] was compared with the Pulkowa klafter eleven times between May 7th and 11th at a temperature of about 53°, and nine times on June 10th and 11th at about 58°.

The reduction of these observations by the method of least squares shows that the probable error of one comparison was

$$\pm 0{\cdot}674\sqrt{\frac{95{\cdot}989}{40-3}}=\pm 1{\cdot}08,$$

which is somewhat large; and for final results at 61°·25,

$$K'=K''_{1.3}+20{\cdot}86\pm 0{\cdot}43,$$
$$K'=K''_{\mathrm{I.II}}+\ 5{\cdot}52\pm 0{\cdot}43.$$

We have now determined directly the lengths of the Pulkowa and Milan klafters, and also by direct observations their difference. It remains to examine as to the consistency of these results; they are, in fact, these:—

$$K' \ -2K_{\frac{1}{2}} \ =162{\cdot}44\pm 0{\cdot}38,$$
$$K''_{1.3}-2K_{\frac{1}{2}} \ =139{\cdot}64\pm 0{\cdot}56,$$
$$K' \ - \ K''_{1.3}= \ 20{\cdot}86\pm 0{\cdot}43,$$

which are not consistent, as the difference of the first and second exceeds the third by 1·94. If we adjust the three results by least squares, we get

$$K' \ =2K_{\frac{1}{2}}+162{\cdot}01,$$
$$K''_{1.3}=2K_{\frac{1}{2}}+140{\cdot}59.$$

But these results are not perfectly satisfactory, as from the manner in which they have been derived we cannot express their probable errors. In order to do this, it is necessary to reduce in one system of equations, by the method of least squares, all the following comparisons, namely:—

27 between $K'_{1.2}$ and $K_{\frac{1}{2}}$,
27 between $K'_{2.3}$ and $K_{\frac{1}{2}}$,
24 between $K''_{1.2}$ and $K_{\frac{1}{2}}$,
24 between $K''_{2.3}$ and $K_{\frac{1}{2}}$,
20 between $K'_{1.3}$ and $K''_{1.3}$,
20 between $K'_{1.3}$ and $K'_{\mathrm{I.II}}$,

where it is to be remembered that $K'_{1.2}+K'_{2.3}=K'+1\cdot48$. Now let

$$\begin{aligned} K'_{1.2}-K_{\frac{1}{2}} &= u+fy, \\ K'_{2.3}-K_{\frac{1}{2}} &= v+fy, \\ K''_{1.2}-K_{\frac{1}{2}} &= u'+f'y', \\ K''_{2.3}-K_{\frac{1}{2}} &= v'+f'y', \\ K''_{\text{I.II}}-K_{1.3} &= x. \end{aligned}$$

Then, further, if K' and $K''_{1.3}$ be compared at the temperature $61^\circ\cdot25+e$,

$$K'-K''_{1.3}=u+v-u'-v'+2ey-2ey'-1\cdot48\,;$$

and if K' and $K''_{\text{I.II}}$ be compared at temperature $61^\circ\cdot25+e$,

$$K'-K''_{\text{I.II}}=u+v-u'-v'-x+2e'y-2e'y'-1\cdot48.$$

Thus we have a system of 142 equations to solve, which finally give a group of seven equations resulting in the following quantities:—

$$\begin{aligned} u &= +79\cdot97, \\ v &= +83\cdot81, \\ u' &= +67\cdot08, \\ v' &= +73\cdot26, \\ x &= +15\cdot28, \\ y &= -\ \ 0\cdot6115, \\ y' &= -\ \ 0\cdot0759\,; \end{aligned}$$

and consequently at $61^\circ\cdot25$ the lengths of the klafters—

$$\begin{aligned} K' &= 2K_{\frac{1}{2}}+u+v-1\cdot48 &&= 162\cdot30, \\ K''_{1.3} &= 2K_{\frac{1}{2}}+u'+v' &&= 140\cdot34, \\ K''_{\text{I.II}} &= 2K_{\frac{1}{2}}+u'+v'+x &&= 155\cdot62. \end{aligned}$$

The reciprocals of the weights of the determinations are

·0624,
·0892,
·1426.

The sum of the squares of the 142 errors is 326·82; consequently the probable error of a single equation is ±1·05, and the probable errors of the determinations of K', $K''_{1.3}$, and $K''_{\text{I.II}}$ are respectively,

$$\begin{aligned} K' &\ \ldots\ \pm1\cdot05\sqrt{\cdot0624}=\pm0\cdot26, \\ K''_{1.3} &\ \ldots\ \pm1\cdot05\sqrt{\cdot0892}=\pm0\cdot31, \\ K''_{\text{I.II}} &\ \ldots\ \pm1\cdot05\sqrt{\cdot1426}=\pm0\cdot40. \end{aligned}$$

If in the results we have now obtained we substitute the value of $2\mathrm{K}_{\frac{1}{2}}$, we get finally for the Pulkowa copy of the klafter,

$$\mathrm{K}' = 2{\cdot}07403658\mathfrak{P} \pm {\cdot}00000041;$$

and for the two lengths of the Milan copy,

$$\mathrm{K}''_{\mathrm{I}\,.\,3} = 2{\cdot}07401462\mathfrak{P} \pm {\cdot}00000045,$$
$$\mathrm{K}''_{\mathrm{I}\,.\,\mathrm{II}} = 2{\cdot}07402990\mathfrak{P} \pm {\cdot}00000051.$$

In a pamphlet by M. Struve, entitled "Vergleichungen der Wiener Masse mit mehreren auf der Kaiserl. russischen Hauptsternwarte zu Pulkowa befindlichen Masseinheiten," 1850, we find it stated that the length of the Pulkowa copy of the Austrian klafter, as determined by Professor Stampfer, is

$$0^{\mathrm{l}}{\cdot}00029 \pm 0^{\mathrm{l}}{\cdot}00020$$

shorter than the legal or standard Vienna klafter, the unit here being the " line " or $\frac{1}{864}$ part of the klafter, that is 2400 millionths of a yard. Hence if $\mathfrak{K}$ be the true length of the klafter, the Pulkowa copy at 61°·25 is

$$\mathrm{K}' = \mathfrak{K} - 0{\cdot}70 \pm 0{\cdot}48,$$

the unit here being, as usual, the millionth of a yard. The date of the certificate is April 1849.

Professor Stampfer also compared the Milan copy of the klafter with the legal or standard Vienna klafter, and with this result, dated October 1856,

$\mathrm{K}''_{\mathrm{I}\,.\,3} = \mathfrak{K} - 0^{\mathrm{l}}{\cdot}0058 \pm 0{\cdot}0005$ . . . 10 comparisons,
$\mathrm{K}''_{\mathrm{I}\,.\,\mathrm{II}} = \mathfrak{K} + 0^{\mathrm{l}}{\cdot}0000 \pm 0{\cdot}0004$ . . . 10 comparisons,

the bar being at 61°·25. This, expressed in millionths of a yard, is

$$\mathrm{K}''_{\mathrm{I}\,.\,3} = \mathfrak{K} - 13{\cdot}92 \pm 1{\cdot}20,$$
$$\mathrm{K}''_{\mathrm{I}\,.\,\mathrm{II}} = \mathfrak{K} - 0{\cdot}00 \pm 0{\cdot}96.$$

It appears from this that the difference of the klafters on the two surfaces of the Milan copy, as determined at Southampton and at Vienna, are in tolerable accordance, being 15·28 in the one case and 13·92 in the other.

But the discordance between the Milan and Pulkowa copies is considerable. Taking the length I . II for example, the difference of the two bars as determined at Southampton is 6·68, while the Vienna comparisons imply a difference of −0·70.

But it is difficult to imagine any constant error in the observations made here, as not only the frequent alterations of the adjustments and daily shiftings of the bars makes this very improbable, but an examination of the tables of errors of the different series of comparisons shows no trace of such error.

Vienna Toise.

The toise marked on the Pulkowa klafter was compared twelve times with the Ordnance Survey toise in September 1867 at temperatures from 58° to 59°, and nine times in December of the same year, the temperature ranging from 39° to 42°.

The observations being reduced by the method of least squares lead to the following result, both bars being at the temperature of 61°·25,

$$T_V = T_0 - 362\cdot73 \pm 0\cdot27,$$

where T_V is the length of the Vienna toise, and T_0 that of the Ordnance toise.

Now the length of the T_0 at 61°·25 is, as given at page 280 of the 'Comparisons of Standards,'

$$T_0 = 2\cdot13166458\mathfrak{Y}.$$

Hence the length of the toise on the Vienna klafter

$$T_V = 2\cdot13130185\mathfrak{Y}.$$

If we compare this with the length of the Prussian toise T_{10}, which (Comp. Stand. page 280) was found by comparisons to be

$$T_{10} = 2\cdot13150911\mathfrak{Y},$$

it appears that the Vienna copy is shorter than the Prussian by 207·26 ; that is,

$$T_V = T_{10} - 207\cdot26.$$

The lengths obtained from these two toises by M. Struve, see 'Arc du Méridien . . . 1860,' vol. i. p. lxxii, are (he calls the bar B′)

$$T_{10} = 863^{\mathrm{l}}\cdot99914,$$
$$T_V = 863\cdot91726\ ;$$

and the difference of these expressed in millionths of a yard is

$$T_V = T_{10} - 202\cdot00.$$

The agreement of this with the Southampton results is not very satisfactory.

The ratio of the klafter to the toise as both marked on the Pulkowa klafter is, according to the observations we have recorded,

$$\frac{2\cdot07403629}{2\cdot13130185} = \cdot973130850.$$

The same ratio, according to the measures of M. Struve, is

$$\frac{840\cdot70342}{863\cdot91726} = \cdot973129556.$$

The same ratio as obtained from the observations of M. Stampfer is (see 'Vergleichungen der Wiener Masse &c.,' page 15)

$$0\cdot97313204.$$

The ratio as determined in the observations at Southampton is therefore intermediate between these.

Standard Bar of the Cape of Good Hope.

The 10-feet Cape standard is a bar similar in construction to the Ordnance 10-feet standard. In April 1844 one hundred comparisons were made between these bars at Southampton, giving the difference of length

$$O_1-B=50{\cdot}08.$$

These comparisons were renewed in January 1868 and September 1869, fifteen being made on six days in the former month at a temperature of about 41°, and fifteen on five days in the latter month at about 59°·5.

The reduction of the observations by the method of least squares gives the difference of length at 62°,

$$O_1-B=51{\cdot}12\pm0{\cdot}25.$$

The agreement of this with the comparisons of 1844 gives much confidence in the stability of these bars, and is almost as remarkable as the result obtained from the Indian bar I_6 (see 'Comparisons of Standards,' page 255).

The Spanish Standard.

The iron four-metre bar belonging to the Spanish Government, which was sent to this country in the autumn of 1869, is a copy of the geodetic standard of Spain. This standard itself was constructed from BORDA'S double-toise No. 1, of which the length is 3·8980732* metres. The description of this standard, and a very full and elaborate exposition of the methods of comparison, is given in the work entitled "Expériences faites avec l'appareil à mesurer les bases appartenant à la Commission de la Carte d'Espagne" (Paris, 1860).

This bar is constructed of two plates of iron in the form of a ⊥, the upright plate being nearly 5 inches in depth, and the horizontal plate 3½ inches in width. These plates are connected by thirteen pairs of angle-pieces. Four thermometers, which are Centigrade and of very excellent workmanship, are attached at the sides of the bar, being of course removable at pleasure. A levelling-apparatus is attached at the upper edge of the bar. The bar is lifted by two pairs of handles; it is not enclosed in a box when in use as a measure, and has no other protection than paint. For travelling it is protected in a very strong box.

On the upper edge of the bar are inlaid five small disks of platinum, and on these are drawn fine lines which mark off the lengths of four metres. The part of each line to be observed is the extremity contiguous to the edge of the bar. The lines are unfortunately not very fine, though otherwise very well drawn.

The following is the certificate of this bar:—

"*Règle en fer appartenant au Gouvernement Espagnol.* Pour chaque degré du thermomètre centigrade elle se dilate de

$$0^{\text{mm}}{\cdot}043193\pm0^{\text{mm}}{\cdot}000009,$$

elle a été comparée avec le règle en platine, étalon géodésique de l'Espagne, lequel étalon l'a été aussi directement avec la règle No. 1 de BORDA déposée, à l'observatoire de Paris. De ces comparaisons il résulte que la règle en fer a de longueur à la température de 21°·935 centigrades,

---

* Base du Système Métrique Décimal, tome iii. pp. 139, 228.

$$4^{m}\cdot0006526\pm0^{m}\cdot000002.$$

"C. IBAÑEZ,
Colonel du génie, attaché aux
travaux géodésiques de l'Espagne."

This bar has been compared in two entirely different manners—first, with two lengths of the Ordnance toise, and secondly with four lengths of the Ordnance metre. The former comparison was rendered possible by the fortunate circumstance that four metres exceed two toises by almost exactly 4 inches, the difference (·013 inch) being easily measured by the micrometers.

Comparisons of the Spanish Bar with the Toise.

In order to effect this comparison the four micrometer-microscopes H, I, J, K were arranged in line at the distances H I=one toise, I J=4 inches, J K=one toise, so that H K=four metres very approximately. The adjustment into a horizontal straight line of the outer foci of these microscopes was a matter of some difficulty, but was finally effected with so much precision that not the smallest error in the comparisons could arise therefrom. It remains to add that the alignment was frequently examined during the course of the observations.

The method of comparison will be understood from the following Table, where the different operations are on successive lines: τ_1 is the mean of the readings of the four thermometers of the Spanish bar before the micrometers are read, e and f are the readings of the Spanish bar by the micrometers H K, τ_2 the temperature of the bar immediately after, and so on. The toise and foot were mounted side by side in the same box. Every reading was made by two observers independently.

Bars.	Microscopes.				Thermometers.
	H	I	J	K	
					τ_1
Spanish . . .	e	. . .	. . .	f	
					τ_2
					t_1
Toise	a	b			
Foot	. . .	b'	c		
Toise	. . .	. . .	c'	d	
					t_2

Let the distances of the zeros of the four micrometers H, I, J, K be

$$HI=P : IJ=Q : JK=R.$$

Then, remarking that the screw-heads of H and I were to the left, and those of J K to the right, we have

$$P+Q+R=S+eh+fk,$$
$$P=T+ah-bi,$$
$$Q=F+b'i+cj,$$
$$R=T-c'j+dk,$$

where h, i, j, k are the values of one division of the respective microscopes. Hence we get

$$S=2T+F+(a-e)h+(b'-b)i+(c-c')j+(d-f)k,$$

where S, T, F represent the length of the Spanish bar, the toise, and the 4-inch space on the foot respectively. This expression gives us the actual difference of length of the bars at the time of comparison. The foot being in the same box with the toise, it is assumed that its temperature is the same as that of the toise.

The comparisons of the Spanish bar with the toise extend over seven days in October, three days in November, and three days in December 1869, in all twenty-three comparisons. The readings of one observer lead to the result, the bars being all at 61°·25,

$$S=2T_0+4I+499{\cdot}63,$$

and those of the other to the result,

$$S=2T_0+4I+499{\cdot}58;$$

and taking the means of the corresponding readings of the two observers, the result is

$$S=2T_0+4I+499{\cdot}60\pm0{\cdot}23.$$

The 4-inch space 4I actually used was the space $[cg]$. The value of this space is, see page 450, at the temperature of 61°·25,

$$[cg]=\tfrac{1}{9}Y_{55}-2{\cdot}73\pm0{\cdot}06.$$

Consequently

$$2T_0+[cg]=4{\cdot}37443869Y_{55}\pm0{\cdot}42;$$

so that finally we have, the Spanish bar being at 61°·25 and the yard at 62°,

$$S=4{\cdot}37493829Y_{55}\pm0{\cdot}48.$$

Comparisons with four lengths of the Ordnance Metre.

In order to effect this, five microscopes were adjusted in line at one metre apart. Ten comparisons were made in October and November 1869. The readings of one observer lead to the result,

$$S=4M_0-58{\cdot}81,$$

those of the second observer to the result,

$$S=4M_0-60{\cdot}62\,;$$

and, taking the means of the corresponding readings of the two observers,

$$S=4M_0-59{\cdot}72\pm0{\cdot}65,$$

both bars being at 61°·25.

Now the ratio of $4M_0$ at 61°·25 to Y_{55} at 62° is

$$4M_0=4{\cdot}377499376Y_{55}\pm0{\cdot}64\,;$$

consequently the Spanish bar at 61°·25 is

$$S=4{\cdot}37493404Y_{55}\pm0{\cdot}91.$$

The two results we have now arrived at as to the length of S differ by $4{\cdot}25\pm1{\cdot}03$. If we combine them with regard to their probable errors, we get finally

$$S=4{\cdot}37493737Y_{55}.$$

By page 280 of the 'Comparisons of Standards,' it appears that at 62°

$$Y_{55}={\cdot}91439143\,\mathfrak{M}\,;$$

whence the length of the Spanish bar is, expressed in metres,

$$S=4{\cdot}00040524\,\mathfrak{M}.$$

We now compare this with the result obtained by Colonel IBAÑEZ at Madrid; according to the certificate accompanying the bar, its length at the temperature of 21°·935 Centigrade is 4·0006526 metres, and the rate of expansion is ·000043193 metre for each degree Centigrade; hence the length of the bar at 61°·25 Fahrenheit, according to the Spanish observations, is

$$4{\cdot}0004071\,\mathfrak{M}.$$

From this it appears that the length of the metre, as given by the Spanish bar, agrees with great precision with that inferred at Southampton from the comparisons of the Belgian and Prussian toises.

The difference between the two lengths obtained for the Spanish bar, first through the teise, and secondly through the metre, suggested the direct comparison of those bars one with the other by means of the approximate relation

Toise+2 inches=2 metres.

For this purpose five microscopes were adjusted in line in the order H, K, G, I, J, at the distances HG=GI=one metre, HK=5 inches, IJ=3 inches. Then the comparison was effected by observing in succession:—

1st, the Ordnance toise under K and J;
2nd, the Ordnance metre under G and I;
3rd, the Ordnance metre under H and G;
4th, 5-inch space [*af*] on foot under H and K;
5th, 3-inch space [*ad*] on foot under I and J.

Hence we have immediately the value of $2M-T-[df]$ at the temperature observed. Ten comparisons were made on the 4th, 5th, and 6th of November, 1869, at temperatures between 50°·73 and 49°·83. The mean of the observations gave

$$2M-T-[df]=277{\cdot}10\pm0{\cdot}25$$

at the temperature of 50°·33. Now, referring to pages 144, 69, and 110 of the 'Comparisons of Standards,' we find that at the temperature of 50°·33

$$2M-T-[df]=276{\cdot}12\pm0{\cdot}38.$$

The agreement of results so totally independent of one another, and each obtained through a very complicated system of observations, must be considered very satisfactory.

Comparisons of the American Metre with the Ordnance Survey Metre.

In the Appendix No. 26 of the United States Coast Survey Report for 1862 will be found, in connexion with the experiments for determining the lengths of the six-metre standard bar and its rate of expansion, mention of six iron metres designated No. 1, No. 2, . . . No. 6, which were compared with the "Committee Metre," or supposed standard metre. These bars are all end measures; the section is a rectangle of 1·13 inch by 0·27 inch.

The unit of length to which all distances measured in the Coast Survey are referred is the French *metre*, an authentic copy of which is preserved in the archives of the Coast Survey Office. It is the property of the American Philosophical Society, to whom it was presented by Mr. HASSLER, who had received it from TRALLES, a member of the French Committee charged with the construction of the standard weights and measures according to the decimal system. This metre is of iron, and was one of the twelve original bars used in the construction of the standard metre by comparison with the *toise*, which had served as unit of length in the measurement of the meridional arcs in France and Peru. It possesses all the authenticity of any original metre extant, bearing not only the stamp of the Committee, but also the original mark (·:) by which it was distinguished from the other bars during the operation of standarding. It is always designated as the *Committee metre*.

The iron metres have in all comparisons been placed on edge, and supported at one fourth and three fourths of their length. The metre compared at Southampton was that marked No. 6.

The length of this metre increased by the two parts of the contact-apparatus was compared with the Ordnance metre. Twenty-eight comparisons were made in January and February 1868, eight in October of the same year, and ten in May 1869. Reducing the observations by least squares, we find the probable error of a single comparison

$$\pm0{\cdot}771;$$

and finally, both bars being at 32°, M_a representing the American metre,

$$M_a=M_0+44{\cdot}37\pm0{\cdot}33,$$

or, both being at 62°,

$$M_a = M_0 + 54{\cdot}55 \pm 0{\cdot}37.$$

It is unfortunate for the success of these comparisons that the expansion of neither of the metres is known by direct experiment. We can arrive at a value of the expansion of M_0 through its comparison with Y_{55}, but the expansion of Y_{55} is known only indirectly. This last bar has been compared with two iron bars, each of which has had its expansion determined by direct experiment. The first of these bars is the Indian 10-feet steel standard. The expansion of Y_{55}, as derived from this source, is

$$6{\cdot}650.$$

But the expansion of this same yard, as inferred from the 10-feet bar OI_1 (see 'Comparisons of Standards,' pages 90 and 227), is

$$6{\cdot}514.$$

The discrepancy between these two is very considerable, especially when, as in the present case, it has to be multiplied by 30. We have, however, no alternative but to adopt the mean as the expansion of Y_{55}, namely 6·582. By page 106 of the 'Comparisons of Standards,' the expansion of a yard of the Ordnance metre is less than this by 0·411; that is, the expansion of the metre for 30° Fahr. is

$$6{\cdot}171 \times 30 \times 1{\cdot}09375 = 202{\cdot}48.$$

Consequently the length of the metre at 32° (see 'Comparisons of Standards,' p. 110)

$$= 1{\cdot}09355096 Y_{55},$$

with a probable error of perhaps ·00000250.

Thus the length of the American metre at 32° is (Y_{55} being at 62°)

$$1{\cdot}09359533 Y_{55}.$$

We may arrive at the length of the American metre otherwise than by using the inferred expansion of the Ordnance metre. For it is stated, in the Report referred to, that in the comparisons of the sum of the six iron metres with the six-metre standard at different temperatures, no variation in the difference of length was found corresponding to different temperatures; that is, the expansion of the iron metres was equal to the expansion of the standard six-metre bar. Now the coefficient of the expansion of the standard was found by very careful experiments to be

$$\cdot00000641.$$

Hence the actual expansion of one of the metres between 32° and 62° would be

$$30 \times 6{\cdot}41 \times 1{\cdot}0936 = 210{\cdot}30.$$

Hence M_a being at 32°, and M_0 at 62°,

$$\begin{aligned} M_a &= M_0 + 54{\cdot}55 - 210{\cdot}30 \\ &= 1{\cdot}09359769 Y_{55}. \end{aligned}$$

This differs but 2·36 from our former result. The mean of the two is

$$M_a = 1·09359651 Y_{55},$$

the probable error of which we may well assume to be about ±2·00.

The length of the American metre No. 6, according to the Report, Appendix No. 26, is, at 32°, less than the "Committee metre" by 3·41 fifteen thousandths of an inch, that is

$$6·31.$$

By more recent comparisons made in March 1869 (kindly communicated by J. E. Hilgard, Esq.), No. 6 is short by 3·2 ten thousandths of an inch, that is

$$8·89.$$

Taking the mean of these, we infer the length of the American standard metre to be

$$1·09360411 Y_{55}.$$

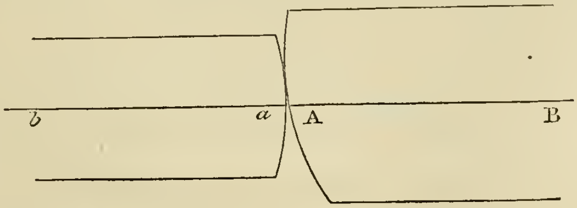
The Report referred to mentions that "besides the Committee metre there is in the collection of the Coast Survey another iron metre of special value, having been made by Lenoir, the artist who performed the mechanical operations in the preparation of the original metres. It is designated as the "Lenoir metre," and has been found, by accurate comparisons with the Committee metre, to be shorter than the latter by $0^{m}·0000258$." This quantity is 28·21 millionths of a yard. Hence the Lenoir metre has for length,

$$\text{Lenoir metre} = 1·09357590 Y_{55}.$$

The Russian Double Toises.

The Russian Double Toise P, of which observations are now to be recorded, is the same bar that was compared at Southampton in 1865. In those comparisons the woollen packing which surrounded the bar was allowed to remain undisturbed. It appears, however, from a subsequent communication from M. Struve, that the bar has been accustomed to be compared with the packing removed, and only a thin covering of cloth remaining wrapped round it. It was therefore judged expedient by M. Struve that the bar should be returned to Southampton for further comparisons to be made without the woollen packing. Moreover, in the comparisons of this bar made in Russia, the contacts are said to have been made at the centres of the disks, and not at the points corresponding to the maximum of length, at which the contacts were made here.

The small terminal cylinder of this bar has a diameter of 0·25 inch, and the centre of curvature of the terminal surface, instead of being, as it should be, in the axis of the cylinder, is 0·025 inch above it. Let A B be the horizontal axis of the cylinder, $a\,b$ that of the cylinder of another bar brought up to contact. Suppose that the centre of the



curved surface of contact of the second cylinder is *in* its axis $a\,b$, and suppose r to be the radius of the spherical surface, R being the radius of the corresponding spherical terminal surface of the cylinder A B of the bar P.

Suppose, in the *first* case, the bars to be so adjusted that the axis $a\,b$ is in the same line with the axis A B. In this case the length of the horizontal projection of the line joining the centres of the spherical surfaces is

$$=\mathrm{R}+r-\frac{\frac{1}{2}e^2}{\mathrm{R}+r},$$

where e is the distance of the centre of the terminal spherical surface of the cylinder above its axis A B, or the distance from A B of that point of the terminal surface at which the normal to that surface is horizontal. But if the cylinder $a\,b$, still maintaining contact, were raised by the quantity e, the common tangent plane at the point of contact would be vertical, and the distance of the centres of the spherical surfaces would be $r+\mathrm{R}$. Hence the bar is apparently shortened by the quantity

$$\frac{1}{2}\frac{e^2}{r+\mathrm{R}}.$$

Secondly, for the case of an actual contact in the centre of the terminal disk of the cylinder of P or in the axis A B, let the axis $a\,b$ be below A B by the quantity

$$\frac{re}{\mathrm{R}}.$$

In this case the contact is in the actual centre of the terminal disk of the bar P, and the horizontal projection of the line joining the centres is

$$\mathrm{R}+r-\tfrac{1}{2}\cdot\frac{\mathrm{R}+r}{\mathrm{R}^2}e^2;$$

so that the error in this case is

$$\tfrac{1}{2}\cdot\frac{\mathrm{R}+r}{\mathrm{R}^2}e^2.$$

To reduce these to numerical results for the bar P, the value of R is 2·00 inches, $e=\frac{1}{40}$ inch. For the contact-apparatus the radius $r=0{\cdot}75\pm{\cdot}03$ inch, obtained, as in the case of the bar P, by the measurement of optical images formed by reflection. Expressed in millionths of a yard, one inch$=27778$; hence, since the same defect exists at each end of P:—

Case 1. When the axes of the cylinders are at the same height,

$$\text{Correction}=\frac{e^2}{r+\mathrm{R}}=6{\cdot}31;$$

Case 2. When the contact is at the centre of the disk of P,

$$\text{Correction}=\frac{(r+\mathrm{R})e^2}{\mathrm{R}^2}=11{\cdot}93.$$

The correction in the latter case is nearly double that in the former, while the actual difference in position of the points of contact in the two cases is but $\frac{1}{133}$ of an inch.

If P were placed in contact with other bars having terminal cylinders of the same diameter and same radius of curvature for the spherical surfaces, but free from the peculiar defect of P, the correction would be, supposing the axes adjusted into the same line, or the touching cylinders at the same height,

$$\frac{e^2}{2R}=4{\cdot}34.$$

If the contacts at the two ends of P were made with very small cylinders, the radius of curvature of whose spherical contact surfaces were *exceedingly small*, then, supposing the axes of these cylinders to be coincident with the axes of the corresponding cylinders of P, the correction to the length of P would be

$$\frac{e^2}{R}=8{\cdot}68;$$

and this quantity is equal to the difference between the maximum length of P and the distance between the centres of its terminal disks.

The comparisons of P in 1865 were commenced, as stated at page 258 of the 'Comparisons of Standards,' in ignorance of the peculiarity of these terminal surfaces. It was attempted to make contacts at the centres of the disks, while at the same time the axes of the cylinder of P and of the contact-apparatus were in one line. It may be assumed that the result would be less than the maximum length of the bar by some quantity intermediate to the two corrections (Case 1 and Case 2) which we have just computed, viz. 6·31 and 11·93. A reduction of the forty observations so made shows the length obtained to have been 10·15 shorter than that which resulted afterwards, when the contacts were made so as to give the maximum length. So far this is perfectly satisfactory.

The new comparisons of P extend over five days in March 1868 and one day in April, the temperature being about 45°; over nine days in August and one in September 1869, temperatures ranging from 61° to 65°. In these comparisons the contacts were so adjusted that the axes of the cylinders of P and of the contact-apparatus were in the same line (Case 1).

The result of the forty comparisons is this, both bars being at 61°·25,

$$P=2T_0-323{\cdot}90\pm0{\cdot}29.$$

If we correct the observations of 1868–69 for the position of the point of contact, so as to give the maximum length of the bar, we get, by adding 6·31,

$$P=2T_0-317{\cdot}59.$$

This differs sensibly from the length determined in 1865, which was

$$P=2T_0-320{\cdot}48.$$

If from the maximum length we would determine the length of the bar measured between the centres of the terminal disks, we have to subtract 8·68; this gives

$$P=2T_0-326{\cdot}27.$$

The Double Toise Q.—This is a bar similar in every respect to P, but without the defect in the terminal surfaces. Eighteen comparisons were made in March 1868 at temperatures from 45° to 46°, and twenty-two comparisons in September 1869 at temperatures between 58° and 61°. These observations, reduced by least squares, give the result,

$$Q=2T_0-360{\cdot}00\pm0{\cdot}40;$$

and this, when compared with the length we have determined for P, viz. $P=2T_0-323{\cdot}90$, is in tolerable accordance with M. STRUVE's determination of the lengths of these bars. According to M. STRUVE, $P-Q=0^{l}{\cdot}01370$, which, expressed in millionths of a yard, is

$$P-Q=33{\cdot}80,$$

while the difference, as determined at Southampton, is

$$P-Q=36{\cdot}10.$$

But there is not the same accordance if we compare the difference between Q and two lengths of the Prussian toise denoted B′. The length of 2B′ (STRUVE, 'Arc du Méridien . . . ,' tom. i. p. lxxiii) is

$$2B'=1727{\cdot}99828;$$

and this exceeds the length of Q, namely 1727·97386, by $0^{l}{\cdot}02442$, which, expressed in millionths of a yard, is

$$2B'-Q=60{\cdot}25=2T_{10}-Q.$$

But, according to the observations made at Southampton ('Comparisons of Standards,' page 273),

$$2T_{10}=2T_0-309{\cdot}04,$$

which, compared with the length of Q determined above, gives

$$2T_{10}-Q=50{\cdot}96,$$

showing a discrepancy of 9·29 millionths of a yard, as though Q had increased in length between the comparisons at Pulkowa and at Southampton.

In order to throw some light upon this discrepancy, in the autumn of 1871, just two years after the comparisons of Q detailed in the preceding paragraph, some further observations were made of Q, the comparisons between it and two lengths of the Ordnance toise being made with the utmost care and circumspection, and the temperature being remarkably uniform during the whole time. The result of these ten comparisons was

$$Q=2T_0-355{\cdot}74\pm0{\cdot}33.$$

In combining our two results for the length of Q we shall not make use of their probable errors, as manifestly they are delusive on account of the existence of some constant source of error. If we are content to take the mean, it is

$$Q=2T_0-357{\cdot}87;$$

but to this we cannot assign its probable error.

If we compare this with our results for P, viz.

$$P=2T_0-323\cdot90,$$

we get for the difference

$$P-Q=33\cdot97,$$

which agrees at least very satisfactorily with the difference of length as determined at Pulkowa, viz. 33·80.

The length of the bar P, as adopted in the 'Comparisons of Standards,' was that assigned to it in STRUVE'S 'Arc du Méridien,' vol. i., viz. 1727·99440. But it appears that more recent comparisons at Pulkowa brought to light a decided alteration of length in P, and show that the length of P is to be taken as

$$P=1727\cdot98756.$$

For the bar Q the length to be used is

$$Q=1727\cdot97386.$$

Measures.	Standard Temperature.	Expressed in Terms of the Standard Yard. — $\mathfrak{Y}$.	Expressed in Inches. — Inch $=\frac{1}{36}\mathfrak{Y}$.	Expressed in lines of the Toise. — Line $=\frac{1}{864}\mathfrak{T}$.	Expressed in Millimetres. — Millimetre $=\frac{1}{1000}\mathfrak{M}$.
	Fahr. Ther.				
The Yard	62°·00	1·00000000	36·000000	405·34622	914·39179
Copy No. 55	61·25	0·99999960	35·999986	405·34606	914·39144
Ordnance Half Klafter	61·25	1·03693714	37·329737	420·31855	948·16681
Klafter, Pulkowa Copy	61·25	2·07403658	74·665317	840·70290	1896·48203
Klafter, Milan Copy [1.3]	61·25	2·07401462	74·664526	840·69399	1896·46195
Klafter, Milan Copy [I.II]	61·25	2·07402990	74·665076	840·70019	1896·47592
Toise laid off on Pulkowa Copy of Klafter	61·25	2·13130185	76·726867	863·91516	1948·84492
Spanish Four-Metre Bar	61·25	4·37493562	157·497682	1773·36363	4000·40522
American Metre No. 6	32·00	1·09359607	39·369459	443·28504	999·97527
Russian Double Toise P, between the centres of terminal disks	61·25	4·26300289	153·468104	1727·99212	3898·05485
Russian Double Toise Q	61·25	4·26297129	153·466966	1727·97931	3898·02596
Cape 10-foot Standard	62·00	3·33328605	119·998298	1351·13491	3047·92941
The Klafter	......	2·07403483	74·665254	840·70219	1896·48043

	Inches.	Millimetres.
Royal Cubit	20·727	526·46
Common Cubit	18·240	463·29

XIV. *Report on the Exploration of Brixham Cave, conducted by a Committee of the Geological Society, and under the superintendence of* Wm. Pengelly, *Esq., F.R.S., aided by a local Committee; with Descriptions of the Animal Remains by* George Busk, *Esq., F.R.S., and of the Flint Implements by* John Evans, *Esq., F.R.S.*

By Joseph Prestwich, *F.R.S., F.G.S., &c., Reporter.*

Received May 16,—Read June 20, 1872.

Contents.

Page
I. Preliminary Observations 471
II. General features of the district; Position of the Cave 481
III. Mr. Pengelly's Report on the structure and contents of the Cave 483
IV. Mr. Bristow's Notes on his survey of the Cave 496
V. Notes on the specimens of the Cave-beds 498
VI. Mr. Busk's Report on the Animal Remains:—
1st Part.—List of the sites in which the remains were found and enumeration of specimens.... 499
2nd Part.—Lists of the sites in which the remains of each species of animal were found 507
3rd Part.—General Remarks on the Animal Remains 517
VII. Mr. Evans's Remarks on the Worked Flints 549
VIII. General Conclusions respecting the Cave 553

I. *Preliminary Observations.*

This Cave, or rather series of enlarged fissures in the Devonian Limestone, was discovered in January 1858 whilst quarrying the rock on the slope of the hill which rises above the small fishing-town of Brixham, near Torquay, in Devonshire. The owner of the quarry had the excavation carried sufficiently far to show that the cave had several branches, and contained bones both on the surface of the stalagmite and in the red loam beneath it. Mr. Pengelly visited the cave soon after its discovery, and, believing it likely to prove of much interest, opened negotiations with the proprietor, with a view to secure the right of exploration. There were, however, obstacles which then prevented this object being carried into execution. Shortly afterwards the late Dr. Falconer, while on a visit to Torquay, was informed of the discovery, and, after a careful inspection of the cave, he was so impressed with the opportunity here afforded of working out completely a new and untouched bone-cavern, that on his return to London he addressed the following letter to the Geological Society. This letter is given at length, as showing the state of the cave question at that period, and the objects to be attained by the exploration of the Brixham Cave.

"31 Sackville Street, W., 10th May, 1858.

"*To the Secretary of the Geological Society.*

"Sir,—I solicit the favour of your bringing the subject of this letter under the consideration of the Council.

"It is well known that a great and popular impulse was given to Geology in this country by the well-directed and eminently successful researches of the late Dr. Buckland on the ossiferous caves of England. After the publication of the 'Reliquiæ Diluvianæ,' the subject in its general bearings was regarded as pretty well exhausted, so far at least as concerned the uniformity of character in the fossil remains found in the caverns, and their being referable to a single geological period. Since 1823 the interest in the subject has gradually fallen off; and it is probably not overstating the fact to say that there is hardly a general geological question in which the majority of geologists in this country take less interest at present than in what relates to the ossiferous caves. The subject has not advanced 'pari passu' with the progress in the investigation of the Upper Pliocene and Postpliocene deposits.

"It was understood that Dr. Buckland before the close of his valuable life had intended to bring out a second edition of the 'Reliquiæ Diluvianæ,' in which some of the questionable views so earnestly advocated in the original work would have been greatly modified; but unfortunately the design remained unaccomplished, and the popular opinions in the cave-districts where collections were amassed have been mainly regulated by the doctrines embodied in the work as published in 1823.

"The consequences have been thus:—the Tunnel caves like 'Kirkdale,' which were haunts of predaceous carnivora, and the Fissure caves like 'Oreston,' that were filled from above, have been popularly regarded as containing the *débris* of the same mammalian fauna, and as having been overlaid with their ochreous loam by the same common agency at the same period. The contents of the different caverns were thus considered as being in great measure duplicates of one another; and the exceptional presence of certain forms in one case and their absence in another were regarded more in the light of local accidents than as significant of any general source of difference. Hence it followed that more attention was paid to the extrication of the bones and to securing good specimens, than to a record of their relative association and the order of succession in which they occurred. The remains have been, in some instances, huddled together in provincial collections—the contents of five or six distinct caves without a discriminative mark to indicate out of which particular cavern they came. Another consequence has been that, being regarded in the light of duplicates, the contents of some of the most important and classical English caverns have been dispersed piecemeal, and, so far as regards them, the evil is now beyond remedy.

"My object in this communication is to bring to the notice of the Council an interesting case of a newly discovered and intact cavern, where the mischief done elsewhere may be partly retrieved, and probably much effected, by combined action well directed.

"Within the last month a new and undisturbed cave has been discovered on 'Windmill Hill,' overhanging Brixham, in the same tract of limestone in which the caverns of Kent's Hole, Anstis Cove, Chudleigh, and Berry Head are found. A brief notice of the discovery appeared in the Exeter 'Western Times' of the 10th ultimo. Mr. Everest and myself went to see it on the 17th ultimo.

" 'Windmill Hill' rises immediately above Bolton Street, in Brixham. The limestone strata crop out on the N.E. side, where they are very cavernous. A vertical channel running up the hill marks the line of a fault (joint?), the walls being separated by a seam of about 2 inches of yellowish loam. Near its base, in quarrying out a foundation for cottages, a concealed cavern was discovered blocked up by loam, rubbish, and breccia—on removing which an open cavity was seen, low and narrow at the mouth, but expanding inwards, and presenting the usual characters of the Plymouth limestone caves; water percolates from above with a copious drip, and the vault and floor are irregularly coated with stalagmite. On a shelving stalagmitic terrace in the interior we saw from a distance a pair of large Cervine horns horizontally imbedded in the stalagmite; and I distinguished bones of *Hyæna*, *Bear*, *Bos*, *Deer*, and *Horse* which had been picked out of the breccia. The interior of the cavern is blocked up by stalagmitic deposit; but from the hollow sound yielded on percussion, it would appear that there are undervaultings as in Kent's Hole. In another direction the stalagmite flooring descends suddenly in a chasm of undetermined depth. There are two external openings nearly at the same level, a considerable distance apart, which would seem to communicate with the same interior hollow; and it is probable that, like Kent's Hole, the Brixham Cave is of great extent with irregular ramifications. As in other similar cases, the principal deposit of fossil bones may be looked for under the stalagmitic floor not yet touched.

"Taking into account the vast richness of Kent's Hole in fossil remains, the dispersion of Mr. M^cEnery's collections, and the grievous fate of the MS. labours of about twenty years of his life*, it is submitted to the Council whether there is not a prospect of equal wealth in this promising and adjoining cave of Brixham, and whether the case is not one deserving of a combined effort among geologists to organize operations for having it satisfactorily explored before mischief is done by untutored zeal and desultory work.

"The importance of following up a case of this description has been forced upon my attention by some of the results of an examination of the cave-bone collections both in England and abroad, in connexion with the investigation of the distribution of the extinct Proboscidea in the European Upper-Tertiary deposits. I have during the last twelve months been more or less occupied with the conditions under which Elephant remains occur in the caves; and having lately returned from a tour in company with my friend the Rev. Robert Everest, during which we had made a *reconnaissance* survey of the caves in, or cave-collections from, the neighbourhood of Bristol, the Mendips, Devonshire, South Wales, Kirkdale, and Cefn, some of the results have appeared of sufficient interest to justify my trespassing on the attention of the Council with this communication. Of these I may mention the following:—

---

* This manuscript was fortunately recovered by Mr. E. Vivian, of Torquay, who, in 1859, published part of it together with seventeen of the original plates; the whole manuscript has since been edited by Mr. Pengelly and published in the Transactions of the Devonshire Association for the Advancement of Science, Literature, and Art for 1869.

"1st. The detection, in considerable abundance in certain of the caves, of the remains of a species of Rhinoceros, equally distinct from the *tichorhine* species of Siberia and of the Glacial period generally, and from the *leptorhine* Rhinoceros of CUVIER, of the subapennine Elephant-bed and Lacustrine deposits of the Norfolk coast. I have seen nearly the entire series of the upper and lower teeth *in situ* in the jaws, and from one of the caves a considerable portion of the skeleton associated with teeth and cranial fragments. The characters distinctive of the form from the species above referred to are so pronounced and so constant, and the material so abundant, that I have no doubts on the subject. I have designated the species provisionally *Rh. hemitœchus priscus**. The interest of the case is enhanced by its presumable relations to some important late investigations of M. LARTET, to which I shall refer in the sequel.

"2nd. Abundant evidence in all the cave-districts of two extinct species of Elephant, viz. *Elephas primigenius* (Mammoth) of the Glacial period, and *Elephas antiquus* of the subapennine period (Norwich Crag and the Astesan)—the former commonly associated in the English caves with the *tichorhine* Rhinoceros, the latter with *Rhinoceros priscus*. I have not observed among the cave-bones any indications of remains of *Elephas* (*Loxodon*) *meridionalis*, nor undoubted remains of *Elephas* (*Loxodon*) *priscus*.

"3rd. In one of the caves, where the evidence is tolerably conclusive that the bones were washed into a fissure about the same time, the following undoubted associations were seen:—

Elephas (*Euelephas*) *antiquus*,
Hippopotamus major,
Rhinoceros priscus,

without the admixture, so far as the collection went, of other species of the same genera.

"4th. In other caves *Elephas primigenius* and the *tichorhine Rhinoceros* were observed, without the admixture of *Elephas antiquus* and *Rhinoceros priscus*.

"5th. In one of the caverns the most important part of the skeleton of an *Elephas antiquus* was found together, supplying a desideratum of the European collections.

"6th. In none of the caves were any specimens observed referable to the *Rhinoceros leptorhinus* of CUVIER, as I regard that species to be limited.

"From what I have seen, I am strongly of the conviction that, with our present advanced knowledge, the thorough investigation of a well-filled virgin cave in England would materially aid in clearing up the mystery, either of the contemporaneity of the Pliocene mammalian fauna with the commencement of the Postpliocene fauna, or of the conditions and associations under which the former was replaced by the latter. M. LARTET, in a late communication to the French Academy, has thrown out a suggestion, the importance of which, if well founded, can hardly be overestimated, that the mixed mammalian fauna of the Glacial period has been made up of two distinct geographical elements—the one a northern division pushed southwards from Siberia and the north of Europe, consisting of the *Mammoth*, the *tichorhine Rhinoceros*, the *Irish Elk*, *Ursus spelæus*, *Bos primigenius*, &c.; the other a southern division projected northward from Mauritania through Spain and France, comprising the existing *African Elephant*, the existing two-horned *Rhinoceros* (*Rh. bicornis*), the *Lion*, *Panther*, two existing *Hyæna*, *Hog*, *Antelope*, *Porcupine*, &c. M. LARTET affirms that Elephant remains from the Quaternary deposits of Spain which had been examined by him belong 'indubitablement à l'Éléphant actuel d'Afrique et au Rhinocéros bicorne vivant aujourd'hui dans la partie australe de ce même continent.'

---

* "Having gone into a detailed examination of the remains, I find that the species *Rhinoceros hemitœchus priscus* is equally distinct from the existing African species and from *Rh. leptorhinus* and *Rh. tichorhinus*."—H. F. For Dr. FALCONER's later observations on the Rhinoceros, see his 'Palæontological Memoirs,' edited by Dr. MURCHISON, vol. ii. pp. 309–403.

"M. GERVAIS has described Rhinoceros remains from the cave of Lunel-viel under the name of *Rh. Lunellensis*, which he affirms are hardly distinguishable from those of the existing two-horned species, the agreement of the teeth being almost complete. M. LARTET states that certain Rhinoceros molars from Kirkdale exhibit the same line of resemblance.

"I have been induced by these circumstances to bring the case of the new Brixham Cavern to the notice of the Council.

"Ever your obedient Servant,
"HUGH FALCONER."

The Council of the Geological Society, not having at their disposal funds for undertaking such a work, addressed a letter to the President and Council of the Royal Society, by whom a grant of £100 was promptly made from the Donation Fund, on the understanding that any specimens obtained should be eventually deposited in the British Museum. This sum was afterwards increased by the liberal donation, through Mr. PENGELLY, of £50 from Baroness BURDETT COUTTS, £5 from Sir JAMES KAY SHUTTLEWORTH, £5 from R. ARTHLINGTON, Esq., and by a further grant of £100 from the Royal Society.

A Committee* of the Geological Society of London—consisting of Dr. FALCONER, F.R.S., F.G.S., *Chairman and Secretary*; Mr. J. PRESTWICH, F.R.S., F.G.S., *Treasurer*; Mr. WM. PENGELLY, F.R.S., F.G.S.; Professor RAMSAY, F.R.S., F.G.S.; Sir CHARLES LYELL, F.R.S., F.G.S.; Mr. R. C. GODWIN-AUSTEN, F.R.S., F.G.S.; Mr. GEORGE BUSK, F.R.S., F.G.S.; Dr. PERCY, F.R.S., F.G.S.; Professor OWEN, F.R.S., F.G.S.; Rev. R. EVEREST, F.G.S.; Mr. BECKLES, F.R.S., F.G.S., and the President and Secretaries of the Geological Society—was appointed to direct the general operations; whilst a Torquay local sub-committee, consisting of Mr. PENGELLY, Mr. EDWARD VIVIAN, Mr. STEWART, Colonel THORESBY, Mr. SHEPPARD, and Mr. HOGG, were deputed by the London Committee to cooperate with them and superintend the actual working of the cave. It is, however, to Mr. PENGELLY that the Committee are indebted for the active and constant superintendence of the work and for the record of each day's proceedings. This gentleman, in fact, saw personally to the execution of the whole work, noted all the physical features, and arranged and tabulated all the specimens found in the Cave, devoting to the investigation an amount of care and time without which it would have been impossible for the London Committee to have obtained the exact record which is now submitted to the Society.

---

* Several of the members elected were, however, unable to attend; and only a limited number of the Committee, whose names are attached to this Report, were able to take part in the prolonged proceedings.

A satisfactory lease of the Cave having been obtained, the services of Mr. Keeping, the experienced fossil collector of the Isle of Wight, were secured, and the work commenced on the 14th July, 1858. The plan of operations laid down by the Committee was progressively to break up and examine the stalagmite floor throughout, and to explore successively and separately each bed beneath it. In this manner it was considered that the succession of beds and the precise position and association of the organic remains would be best determined.

In the course of the summer the cave was visited by several members of the London Committee, and in September 1858 the work had so far advanced that the following Report was drawn up by Dr. Falconer, in conjunction with Professor Ramsay and Mr. Pengelly.

"*Report of Progress in the Cave.*

"Having lately made a joint inspection of the 'Windmill Hill Cavern' at Brixham, we think it may be of interest to the London Committee to know our opinion of the progress already made in the excavations, and of the probable prospective results. We examined the cavern in company with Mr. Pengelly, F.G.S., under whose zealous superintendence the operations are conducted, and of Dr. John Percy, F.R.S., who during his residence at Torquay has taken an active and lively interest in the exploration. Most of the points to be discussed in the sequel were freely discussed among us, and there was but little difference of opinion as to the bearing of the observations and the best plan of carrying on the work for the future.

[Then follows first an account of the extent and structure of the cave, so far as then explored, with a sketch ground-plan by Professor Ramsay. The later surveys and fuller description render it unnecessary to repeat this preliminary description. See Palæontological Memoirs, vol. ii. p. 492.]

"Regarded in a general way, the Brixham Cave may be considered as partaking of the tunnel character of the Kirkdale Cave in the 'Flint-knife Gallery,' and of the fissure character of Kent's Hole and the Gower Caves in the 'Reindeer Gallery.' No vertical flues ascending towards the summit of the cliff have as yet been detected in the explored parts, such as were found in the Oreston Cave and in Paviland.

"2. *Workings.*—The conduct of the excavations was consigned by the London Committee to Mr. Prestwich and Mr. Pengelly. The Committee, fully impressed with the probability of remains of different periods being met with at the different levels in the cavern floor, determined from the outset on working the upper deposits horizontally inwards, as far as might be practicable, on the same horizon, and then of working the lower deposits successively in the same manner. In this manner they considered that they would avoid the risk of confounding the remains of different levels, which is apt to take place when excavating cave-bottoms vertically down to the rock floor, and which has vitiated the results obtained in many other cave-explorations, more especially in regard of the contested position of human industrial remains. The excavations were commenced on the 14th July by Mr. Keeping, of the Isle of Wight, deputed by Mr. Prestwich for the purpose; and they have been conducted with such vigour and success that within six weeks the stalagmite floor of the 'Reindeer Gallery,' together with the ochreous cave-earth deposits below it, was entirely broken up, and the floor of the 'Flint-knife Gallery' explored from its interior termination to the external 'central entrance.' The 'Pen Gallery' was also laid open from its commencement on to the 'Big (south) Chamber,' and on a rough estimate about 1500 bones were exhumed between the 14th July and the 23rd August.

"3. *Successive floor deposits.*—We are able to enter on this part of the subject only in a general way, having taken no precise measurements of the incomplete sections at different intervals in the galleries. Where all the deposits are present, the following section was yielded:—

1. Layer of stalagmite of irregular thickness.
2. Cave-earth (ochreous), with limestone breccia.
3. Ochreous cave-earth, with comminuted shale.
4. Rounded gravel, depth undetermined.

"Occasional water-worn pebbles were found mingled with the organic remains in the upper deposit of cave-earth No. 2. The drip from the roof in wet weather is copious in all the fissure galleries, and the floor in these cases is covered with a cake of stalagmite; while in the intersecting Tunnel Gallery there is little or no drip from the roof, and the surface of the cave-earth is uncovered.

"4. *Organic Remains.*—Mr. Pengelly estimates that about 1500 bones had been exhumed during the first six weeks of the workings. A large number of these, however, belong to skeletons of small animals, like the Rabbit and Fox, found near the surface; we consider that the great harvest of remains will be found in the low-level deposits which have not yet been penetrated. Remains of the following animals were identified by Dr. Falconer:—

"*Rhinoceros tichorhinus.*—Detached upper and lower molars, in considerable numbers, of young and old animals; an astragalus bearing distinct marks of superficial gnawing, dug up in our presence.

"*Bos.*—Species undetermined; teeth, jaws, and other bones.

"*Horse.*—Species undetermined; a few remains.

"*Cervus tarandus.*—The cranial box of the skull found near the surface by the owner on the first discovery of the cave, and a very fine entire antler imbedded superficially in the stalagmite near the intersection of the galleries E E and F F (Reindeer and Flint-knife Galleries) over the Ebur chasm*.

---

* Formed by a thin crust of stalagmite stretching across a cavity in the cave-earth.

"Fragments of antlers of other Deer; species undetermined.

"*Ursus spelæus.*—Lower jaws of young and old individuals with numerous detached canines and other teeth in fine preservation. A superb specimen of a left hind leg, comprising the femur, tibia, and fibula folded together, with the patella and astragalus *in situ*. These were found near the 'Ebur chasm;' and the other parts of the skeleton may be looked for when that portion of the cavern is dug up.

"*Hyæna spelæa.*—Teeth, fragments of the skull, lower jaws, and other bones.

"The above is nothing like a complete list of the animal remains found in the cave; but, considering that the workings have hitherto been restricted to the least productive and superficial deposits, it will suffice to show that the anticipations formed of the cavern were not too sanguine, and that the excavations are well worthy of being followed up vigorously; some of the results already arrived at are of great general interest.

"5. *Human Industrial Remains* (?).—Several well-marked specimens of the objects called 'Flint Knives,' and generally accepted at the present day as the early products of rude Keltic or pre-Keltic industry, have been exhumed from different parts of the cavern, mixed in the ochreous earth indiscriminately with remains of *Rhinoceros*, *Hyæna*, and other extinct forms. One of these so-called 'Flint Knives' was brought up from the deposit No. 2 from a depth of 30 inches below the superficial stalagmite No. 1. We failed in detecting evidence that these so-called 'Flint Knives' were of a different age, as regards the period of their introduction, from the bones of the extinct animals occurring in the same stratum of cave-earth, or that they were introduced into the cavern by different agencies. SCHMERLING discovered, in the caves of Engis and Chokier, near Liége, well-marked flint knives and arrow-heads mingled, in the ochreous mud and gravel, with the bones of extinct mammalia, which he inferred had been washed in by the agency of running water; these included *Mammoth*, *Rhinoceros*, and *Hyæna*. DELPON and JOUANNET have made corresponding observations as to a similar mixture in the caves of Quercy and Périgord; MARCEL DE SERRES, DE CHRISTOL, TOURNAL, and DUMAS have inferred the same, in numerous caves in the south of France. The attention of Mr. PENGELLY has been closely directed to a careful and minute observation of the circumstances of the association in the Brixham cavern. The results of the exploration of each day are carefully put aside and labelled; and it may be anticipated that data will be arrived at for settling the disputed question of the contemporaneous introduction, or otherwise, of the supposed human industrial objects into the cavern along with the remains of the extinct mammalia.

"6. One result of great interest has already been brought out, namely, the superposition of undoubted remains of the Reindeer above the so-called 'Flint Knives,' from which the inference arises that the 'Reindeer' continued to be an inhabitant of Britain after the appearance of man in this island. A fine horn of a Reindeer, nearly perfect from the basal burr to the terminal branches of the beam, and presenting a bez-antler 17 inches long terminating in palmated snags, was discovered, superficially imbedded in the stalagmite, close to the 'Ebur chasm.' Near the same place a flint knife was brought up from the ochreous earth 30 inches* below the stalagmite. Professor OWEN has noticed the occurrence of Reindeer remains in the 'Ash Hole' cavern of Berry Head, explored by the Rev. Mr. LYTE; Dr. FALCONER has identified skulls of the same species found in the Mendip caverns; and Major WOOD, of Stout Hall, has discovered skulls of it in the caves of Spritsail and Paviland, in Gower.

"In these instances there was no indication of their association with man; but in the Brixham cavern the evidence, so far as it goes, clearly tends to show that the antler in question was one of the latest introductions into the cavern before the (road) Entrance was blocked up by the rubbish, and long subsequent to the entombment of the objects called 'Flint Knives.'

"7. On the whole we consider the progress made to be highly satisfactory, and the promise of future results to be so encouraging as to merit the best efforts of the Committee to provide the means for following up the excavation. The grant from the Royal Society, together with Miss BURDETT COUTTS's liberal donation, however carefully husbanded, will not cover the very moderate scale of expenditure within which the operations are at present conducted beyond the month of December. A further grant may with some confidence be expected from the Royal Society next summer; but we invite the earnest attention of the Committee to devise ways and means to meet the expense of the excavation until then.

(Signed) "H. FALCONER, M.D.
"ANDREW RAMSAY.
"*9th September*, 1858." "WM. PENGELLY."

In November 1858, on the application of the Committee for assistance in making an exact plan of the cave, the Director-General of the Geological Survey, the late Sir RODERICK MURCHISON, obligingly instructed Mr. BRISTOW, F.R.S., a member of the Survey, to proceed to Brixham and carry out the objects the Committee had in view.

An excellent plan of the cave and various transverse sections were taken by Mr. BRISTOW, showing the form of the cave and the mode in which the cave-deposits were arranged.

At that period the whole of the stalagmite, the bed of breccia, the cave-earth, and part of the lower bed of gravel had been removed. After the removal of the whole of the latter bed, and the cave had been completely emptied, the Committee employed Mr. BOVEY, of Brixham, to complete the survey of those portions of the cave worked out subsequently to Mr. BRISTOW's visit. The lower lines in the sections, and the central lines in the plan, form the additions made by Mr. BOVEY. The result of this combined work has been carefully correlated and reduced to a small scale by Mr. JORDAN, under the superintendence of Professor RAMSAY.

The map is compiled, from those of the Geological Survey and Dr. HOLL, by your reporter, who has also introduced into Mr. BRISTOW's sections some few alterations in the form of bed No. 4 and position of s', which were necessary in order to make them in accordance with Mr. Pengelly's observations and sections, which give many special features that could only have been noted, as they were by him, during the progress of the work.

---

* Should be 9 inches. The right figure is given in Dr. FALCONER's notes.

The Report drawn up for the Committee by Mr. Pengelly consists of three parts:—1st, "Topographical and Historical details," the essential points of which are embraced in the next chapter; 2nd, "Results of the Exploration," which contains a valuable and minute account of the contents of the cave and of the finding and distribution of the organic remains,—this is given in full in § III.*; 3rd, "Of Inferences from the facts discovered,"—although these have not been adopted by the Committee, the essential theoretical views† of Mr. Pengelly on the origin of the cave and its contents are given and discussed with others in the "General Conclusions" (§ VIII.). In addition to this, Mr. Pengelly handed in a "Daily Register"‡, containing an account of each day's discoveries or "finds."

Mr. Bristow's survey was also accompanied with some remarks on the structure and origin of the cave. Much of this is superseded by Mr. Pengelly's more continued and complete record; but those of Mr. Bristow's remarks and opinions are introduced which serve either to amplify or more fully explain some point, or where the conclusions to which they lead are different. His descriptive notes are given in § IV.

The Flint Implements have been made the subject of some interesting observations by Mr. John Evans, and the more important specimens are figured (§ VII.).

As it was at the instigation of the late Dr. Falconer that this investigation, in which he took a deep interest, was undertaken, the Committee had looked forward, but for his untimely and lamented death, to a report on the animal remains from his pen. From the same hand also they had hoped to receive the General Report. With respect to the accomplishment of the first object, Mr. George Busk kindly took charge of his friend's notes on the subject, and has furnished the Committee with a valuable Report on the bone remains found in the cave, together with some important observations on the species of fossil Bears (§ VI.).

The Treasurer was deputed by the Committee to describe the lithological specimens and to draw up the General Report. By the terms of the grant the object of this inquiry was the "Exploration of the Brixham Cave." By this your reporter understands such a complete description of the cave and of its organic remains, and such a discussion of its origin, as may serve as a basis for further study and for more extended generalization. Referring, therefore, for information on the first of these essential points to the communications of Mr. Pengelly and Mr. Busk, he has limited his general observations to conclusions incidental to this special case, deeming it better to abstain from any more general considerations foreign to the immediate object of the inquiry (§ VIII.).

* With a very few alterations to avoid repetitions and to obtain uniformity of references, and by the introduction into Table I. of the dates taken from the Daily Register.

† These, we have reason to hope, will form the subject of a separate memoir elsewhere by Mr. Pengelly.

‡ Compiled from the notes kept by him and by Mr. Keeping, who was also always on the spot. The "finds" of each day are tabulated in Mr. Pengelly's Tables and Mr. Busk's Report, Parts 1 & 2.

II. *General features of the district; Position of the Cave.*

The town of Brixham is situated at the entrance of a narrow valley on the southern shore of Torbay, nine miles south of Torquay (see Map, Plate XLI.). The small stream which flows through the town into the harbour has a course only of 2½ miles. The first part is over Devonian slates and grits; at Brixham it passes through a belt of limestone about a mile wide, and which, running parallel with the coast, terminates at Berry Head. To the north of the town is Furzeham Hill, 177 feet high. To the south, Windmill Hill (on the north-western angle of which the cave is situated) and Heath Hill rise respectively to the height of 175 and 190 feet; while to the westward, Parkham Hill is 164 feet above the level of the mean tide (Ordnance Survey maps). A small affluent passes between Windmill and Parkham Hills. The watershed between Brixham valley and that of the Dart rises to the height of from 400 to 550 feet.

Mr. PENGELLY states that "Windmill Hill is entirely composed of impure thin-bedded, cleaved and jointed limestone belonging to the Devonian system,"—one set of joints having a "prevalent direction of N. 82° E. to S. 82° W., and the second running nearly magnetic north and south. In fact they have the bearings of the Brixham valleys." "The planes of the first underlie or dip southward, whilst those of the second are approximately vertical. The stratification and cleavage-planes intersect at an angle of about 40°, and with the joints cause the rock to break readily into pieces of small dimensions. The dip of the strata is about 38° north, 10° east, magnetic.

"Devonian slates, frequently traversed by thick veins of quartz, are largely developed at and south of Mudstone Bay; and a considerable mass of greenstone occurs at Sharkham Point, the headland south of Berry Head*.

"Deposits of iron-ore occur in various parts of the district. That at Sharkham Point is the red or anhydrous hematite, whilst that found elsewhere is the brown or hydrous variety. The most important deposit of the latter occurs at Furzeham. There are no indications of iron on Windmill Hill.

"A raised beach extends along the northern slope of Berry Head Hill, about 30 feet above the sea-level. It is chiefly composed of limestone pebbles, but fragments of flints and other rocks are by no means rare." There is another 'raised beach,' on the same relative level, at Hope's Nose, near Torquay, which contains shells identical with those at present existing in the adjacent sea†.

Mr. PENGELLY further states that the district is generally free from all superficial deposits, except occasionally small depressed patches of sand and gravel, which also sometimes fill narrow fissures in the limestone and extend to considerable depths. The gravel is composed largely of fragments of quartz, greenstone, and other rocks not of immediate derivation. No fossils have been found in the sand or gravel. A red loam also caps most of the limestone hills. Peaty masses with prostrate trunks and erect stumps of trees occupy the mouths of most of the valleys terminating in Torbay, and extend beneath the sea to at least the depth of 5 fathoms, that is to the entrance of the Bay. This does not occur off Brixham; but traces of it were found a short way up the valley*.

---

* On the Geological Survey Map another mass of greenstone is marked near the River Dart.

† Mr. GODWIN-AUSTEN gives the following list of them:—*Cardium edule*, *C. tuberculatum*, *Cyprina islandica* *Modiola modiolus*, *Ostrea edulis*, *Pecten maximus*, *P. varius*, *Venerupis decussata*, *Littorina littorea*, *Murex erinaceus*, *Patella vulgata*, *Turritella terebra*, and *Serpula* (Trans. Geol. Soc. vol. vi. p. 442).

The entrance of the cave, which is on the line of a north and south joint (Plate XLI. *f*, fig. 1), was calculated by Mr. BRISTOW trigonometrically† to be 93 feet above high-water mark; whilst Mr. BOVEY made it 94 feet 11 inches by levelling, or about 66 feet above the level of the stream in the valley in front of the cave. It is therefore rather more than halfway to the top of the hill, the slope of which is without steep escarpments, but with a terrace at the level of 150 feet (Plate XLI. fig. 2‡).

The work of exploration was completed in the summer of 1859, the cave having been then emptied so far as it could be followed, although Mr. PENGELLY observes "that galleries certainly extend beyond the point reached by the workmen." It is probable that the hill is in fact traversed by a number of such fissures.

Respecting the manner in which the exploration was conducted, Mr. PENGELLY remarks:—"It was decided first to remove the stalagmitic floor, then the entire bed immediately below (if not of inconvenient depth) horizontally throughout the length of the cavern, or so far as practicable; this accomplished, to proceed similarly with the next lower bed, and so on until all the deposits had been removed.

"The more effectually to guard against the chance of error, the materials were first carefully examined *in situ*, after which they were taken at once outside the cavern, where they underwent a further inspection. In no instance were they removed, for even temporary convenience, from one part of the cavern to another.

"Whenever a bone or other article worthy of preservation was found, its situation (that is to say, its distance from the mouth or entrance of the gallery in which it occurred, as well as its depth below the surface of the bed in which it lay) was carefully determined by actual measurement. In order to their identification, the specimens were all numbered; those which were found in the same place received the same numeral, and were packed in one and the same box, so that at the close of the exploration the number of boxes indicated the number of localities in which fossils had been found; the boxes were also distinguished by numbers, each bearing that which each specimen within it bore. Finally, an entry of each box was made in a journal, in which were registered the number and situation of the specimens it contained, with the date on which they were found, and occasionally a few remarks respecting them."

---

* For fuller accounts of the geology of the district the reader can consult SEDGWICK and MURCHISON's paper "On the Older Stratified Deposits of Devonshire," Trans. Geol. Soc. 2 ser. vol. v. p. 633; R. C. GODWIN-AUSTEN "On the Geology of the South-east of Devonshire," *ibid.* vol. vi. p. 431; Dr. HOLL "On the Older Rocks of South Devon," Quart. Journ. Geol. Soc. vol. xxiv. p. 400.

† The observations were made during extremely stormy weather.

‡ The valley line is represented in the figure as descending too low.

III. Mr. Pengelly's *Report on the Structure and Contents of the Cave.*

Character and Extent of the Cavern.—On the termination of the work the cavern was found to be comprised within a space measuring 135 feet from north to south and 100 from east to west, to consist of a series of galleries with two small chambers, and to have four external entrances, one in the northern and the remaining three in the western slope of the hill (see Plate XLII.).

The northern (original) entrance is that which from the beginning to the end of the work was used as the working entrance. It was commonly called the "Dyer's* Entrance." The photograph was taken the day before the work began (Plate XLI. fig. 1)†.

The galleries, which measure from 6 to 8 feet in greatest width and from 10 to 14 feet in height, resolve themselves into two sets or systems, having strictly the same bearings as the joints of the Devonian rocks of the district.

It is not intended to imply that the absolute dimensions of the cavern have been ascertained. Narrow ramifications probably extend very far into the hill‡, and there is reason to believe that the cavern as it now exists is but a fragment of what it once was.

Principal Branches of the Cavern.—It was found convenient to give names to the various divisions of the cave; and though some of them may be considered somewhat fanciful, they are retained here in order to prevent confusion.

The Reindeer Gallery (that proceeding southward from the north entrance) is 135 feet in length, and is divided into a northern and a southern branch by a narrow passage 15 feet long, and varying from 15 to 18 inches wide. This part of the gallery was known as the *Crystal Gorge*, because when discovered its northern end was completely filled with stalactitic matter.

The Steep Slide Hole descends somewhat spirally (from the Reindeer Gallery) at an angle of upwards of 40°. It gradually diminishes in width, and at the depth 40 feet is too narrow for working.

Kelly's Gallery (which also branches from the same part of the Reindeer Gallery) is several feet wide at the entrance, contracts somewhat rapidly towards the inner end, and ultimately becomes a small almost vertical flue, which probably reaches the surface of the hill.

---

* This name was given to this entrance from the circumstance that the owner of the quarry was a dyer of the name of Philp. We have changed this to "road" or "north" entrance as better indicating its position.

† Mr. Pengelly says that "the distances in the Reindeer Gallery, including those in Tables I. and IV., were all measured from the point where the foot of the hill met the road, *i. e.* the actual commencement of the cavern as we first knew it, *i. e.* the "Dyer's Entrance." The photograph of the Cave represents the Reindeer Gallery about 22 feet south of the Dyer's Entrance, *i. e.* the road."

‡ "Some of the galleries certainly extend beyond the points reached by the workmen, but they had become so very narrow as to render the work extremely toilsome; in no instance, however, was the excavation abandoned until long after it had ceased to yield fossils or other objects of interest."

The *Pen Gallery* is a small tunnel with a continuous limestone floor, and connects the West and South Chambers.

The *Flint-knife Gallery* opens out of the right or west wall of the Reindeer Gallery at 64 feet from the north entrance. It is about 7 feet wide, throws off two narrow branches on the south and one on the north, extends almost due west for about 50 feet, where it becomes somewhat funnel-shaped, and terminates in the West Chamber.

Keeping's and Munday's Galleries are lateral branches of the *South and West Chambers* respectively, and are without any features requiring description.

Near the centre of the South Chamber a short pillar-like mass of limestone connects the floor and roof.

Of the *two external entrances* which open out of the West Chamber, the base of one is slightly above the vertex of the other. They were known as the first and second West Entrances respectively.

During the excavation of King's Gallery the entire mass of rock which formed its northern or outward wall, and which was estimated at one hundred tons, fell and stopped all further progress in that direction.

The roof of the Cavern.—The northern end of the Reindeer Gallery was an open cutting in the limestone without the trace of a roof for the first 5½ feet, and it had only a partial roof for the next 10½ feet, and terminated as an open fissure 16 feet south of the road. The hole through which Mr. PHILP first entered was 4 feet still further south. Excepting in the Flint-knife Gallery, a well-marked longitudinal joint everywhere exists at the vertex of the roof, through some parts of which, especially in the Reindeer Gallery, a somewhat copious drip, quite free from earthy admixture, enters in wet weather. Though distinctly marked in the Steep Slide Hole, this roof-joint is too close fitting to allow even the passage of water. A transverse or north and south open fissure, about 18 inches wide, crosses the roof of the Flint-knife Gallery, and corresponds with the narrow lateral branches which open out of the north and south walls of this division of the cavern. When discovered it was filled with angular blocks of limestone, having fine earthy matter between them. Its situation is shown at "*m*," fig. 2, Plate XLIII.

The walls of the two principal Galleries.—Vertical cross sections taken in various parts of the two principal galleries (see figs. A, B, C, D, & G, Plate XLIII.) show that the walls are very irregular, whether different sections are compared with one another or the outline of any one alone is considered. Of those taken in the Reindeer Gallery the axes are vertical (figs. A to F); whilst in the Flint-knife Gallery they dip or underlie towards the south (fig. G), thus agreeing with the joints the directions of which they respectively have.

Notwithstanding this irregularity, however, there are certain characters which the walls possess everywhere. For example, all their angles are rounded off; their surfaces, especially where they are concave, have a sort of rough polish, like that produced by running water carrying detrital matter in a sensibly horizontal direction; and at corresponding levels in the opposite walls there are two pairs of broad deep grooves, which, without sensible inclination, run along the entire length of the galleries (see *a a* & *b b*, figs. D, E, G, Plate XLIII.). In the *Pen Gallery* the lowest pair only exists. The abrasion or polish of the walls is most strongly marked in the Steep Slide Hole.

The Limestone Floor of the Galleries.—The limestone walls, as seen in figs. D, E, F, commonly curve inwards below the lowest pair of grooves; but instead of meeting so as to form a continuous floor, they remain separated by a central longitudinal fissure, which varies from 3 to 18 inches in width, and averages about a foot. In the eastern 14 feet of the Flint-knife Gallery the floor is perfectly continuous, there being no trace of a fissure, nor indeed of any line of fracture (fig. G). Towards the northern end of the Reindeer Gallery (fig. C) there are two such floor-fissures, and each wide enough to admit of working to a greater depth than elsewhere in the galleries.

A north and south fissure crosses the floor of the West Chamber (Plate XLIII. fig. 2, *m*), and communicates with the South Chamber through an "undervaulting;" this, though somewhat wider than the floor-fissures are elsewhere, gradually narrows downward.

The Ceiling.—Throughout a considerable part of both the north and south branches of the Reindeer Gallery, what may be called a *Stalagmitic Ceiling* (*s*′) extends horizontally from wall to wall. It varies from 6 inches to upwards of a foot in thickness; and through the considerable openings which occur in it an unoccupied space is seen above, which varies from 15 inches to more than 2 feet (*o*, figs. C, D, E, & fig. 1). In several instances pieces of old stalagmite, angular, subangular, and well rounded, together with small pieces of quartz and limestone, are firmly cemented to its inferior surface.

A few stalactites depended from the roof in the Reindeer and Pen Galleries, and also in the South Chamber; and here and there the same branches of the cavern were ornamented with pillars and curtains of the same material.

A Floor of Stalagmite (*s*), varying in thickness from a few inches to upwards of a foot, commenced in the Reindeer Gallery about 17 feet south of the entrance (that is, 1 foot within the commencement of the unbroken roof), and extended over the detrital accumulations southwards into, but not through or beyond, the Crystal Gorge. A lateral branch of this "floor" extended into the Flint-knife Gallery, where it gradually thinned out to a mere film (Plate XLIII. figs. 1 & 2).

It was generally of a pure white or cream colour, unsoiled by earthy matter; but in a few instances soil-stains were conspicuous. Vertical sections showed it to be very distinctly laminated, the layers varying in thickness, and being sometimes alternately crystalline and earthy. It attained its maximum thickness near the northern end of the

Crystal Gorge. Similar floors existed in the Pen and Keeping Galleries, and in the South Chamber, but not elsewhere.

The detrital accumulations in the principal galleries were separable into distinct beds, and were respectively designated the "First," "Second," "Third," and "Fourth" (see sections, Plate XLIII.).

The First Bed was that mass of small angular fragments of limestone, cemented into a compact breccia by carbonate of lime, which filled the northern end of the Reindeer Gallery when the cavern was discovered. It was about 34 feet long, and from the commencement of the entire roof formed an inclined plane dipping southwards to a little beyond the mouth of the Steep Slide Hole, where it terminated.

The Second Bed was a thin layer of blackish matter, which the workmen were accustomed to speak of as the charcoal bed. Dr. PERCY, however, who saw it *in situ*, stated that it did not contain any thing entitling it to this appellation. It extended from 12 feet south of the entrance to near the mouth of the Steep Slide Hole, and lay immediately beneath the first bed. Its greatest thickness did not exceed 1 foot, which it attained about 2 feet from its commencement, and it gradually thinned out southwards. No organic remains were found in it, nor did any thing resembling it occur elsewhere in the cavern.

The Third Bed, sometimes called the *Loam Bed* and the *Bone Bed*, consisted of a reddish-brown, tenacious, clayey loam, and contained a large number of angular and subangular fragments of limestone, which varied in size from very small bits to masses weighing even a ton. The large blocks were found only in the West and South Chambers, and in the gallery connecting them, where the angular character of the roof, unlike that which obtained elsewhere, as well as the fact that the blocks were confined to the upper portion and surface of the deposit beneath, showed that they had fallen from above at a comparatively recent period. *Pebbles* of quartz, trap, and limestone were of frequent occurrence, especially in the Flint-knife Gallery and in the West Chamber. *Nodules of iron-ore*, well rounded, as if by travel, were occasionally met with in both the principal galleries. Dr. PERCY pronounced them all to be specimens of the brown or hydrous hematite. Fragments of stalagmite, apparently portions of an old floor, were also found in this bed in the West Chamber, the western part of the Flint-knife Gallery, and in the Steep Slide Hole—portions of the cavern in which it does not appear that a floor of this kind ever existed. Some of them measured as much as 18 inches square, and from 3 to 4 inches thick. At least a cartload of this material must have been found.

Ordinarily the third bed measured from 2 to 4 feet thick, the variations being due partly to inequalities in the surface of the deposit next below, and partly to the fact that the latter was invariably from 4 to 9 inches lower at the sides than in the middle of the galleries.

Besides the inequalities just alluded to, there were two of a more marked character:

thus at about 15 feet south of the north entrance, and adjacent to the west wall of the Reindeer Gallery, the "bone-bed" occupied a funnel-shaped pipe (*c*) 5 feet deep, 12 and 4 inches in diameter at its upper and lower ends respectively, and penetrating vertically downwards into the bed below; and in the West Chamber the loam filled in the inferior bed a basin-shaped hollow (*d*) almost as large as the chamber itself, and upwards of 4 feet deep (fig. 2, Plate XLIII.).

The West Chamber and the adjacent portion of the Flint-knife Gallery were completely filled to the roof (Plate XLIII. fig. 2). It may be doubted, however, whether the materials above what may be called its ordinary level should be regarded as really a portion of the third bed. They consisted of thin fragments of limestone and a small quantity of dry inadherent earthy matter of a drab colour, instead of the tenacious reddish loam so characteristic of bone-caverns. . . . . . It is probable that much of these materials fell through the cross fracture (*m*) in the roof of the Flint-knife Gallery, and perhaps at a comparatively recent period.

With the exception of most of those found in the "basin" just mentioned every unequiaxed object lay with its longest axis in the plane of the bed, and the shortest at right angles to it; in other words, their centres of gravity occupied the lowest position possible. In the basin "*d*," on the contrary, such objects were commonly found sticking in the loam at right and various other high angles to the plane of the horizon.

At the northern end of the Crystal Gorge, within the vertical range, and forming part of the third bed, there were six or seven plates of compact, crystalline, soil-stained, finely laminated stalagmite, extending horizontally from wall to wall one over the other in a vertical series, and alternating with an equal number of interstratified layers of the ordinary reddish loam, which, as well as the plates of stalagmite, varied from half an inch to upwards of an inch and a half in thickness.

The Fourth or Gravel Bed was in all cases the basis on which the third was deposited; it consisted mainly of pebbles of different kinds of rock,—quartz, greenstone, grit, and limestone, mixed with small fragments of shale common in the Brixham district. In short it was made up essentially of such materials as were amongst the accidents of the bed above, and which, with the sole exception of the limestone fragments, were not derivable from Windmill Hill. Two of the pebbles were so remarkably round that, in addition to samples of the gravel, it was thought desirable to preserve them amongst the specimens illustrative of the cavern. The first is a sensibly spherical red sandstone ball, about 1½ inch in diameter, and was found near the upper surface of the bed at the mouth of the Steep Slide Hole. Balls of this character, probably of concretionary origin, are common in the New Red Sandstone at Dawlish and other parts of south-eastern Devonshire. The second is larger, less spherical, and composed of very compact grit approaching to quartzite. It was found in the West Chamber in the upper portion of the bed. Though in most cases a loose aggregation of pebbles, the gravel was occasionally cemented into a conglomerate. In the easternmost 14 feet of the

Flint-knife Gallery the gravel rested on a continuous limestone floor, but elsewhere its base has not been reached, the floor-fissure being too narrow to allow of working to the bottom.

The loam which, as previously mentioned, occupied the "basin-shaped hollow" (*d*, fig. 2) in the fourth bed was not in contact with the lower part of the western wall of the West Chamber, but was separated from it by a steep talus of gravel, the summit of which was a very few inches below the base of the first west entrance, and about as much above the vertex of the second. Hence the former entrance was filled exclusively with materials of the third bed, and the latter with those of the fourth. This was the highest level to which the gravel attained.

Lines of Inclination in the two principal Galleries.—The longitudinal axes of the limestone floors of the principal galleries were sensibly horizontal. Though, as has been remarked, the "wall-grooves" were without *sensible* inclination, careful measurements showed that both pairs dip, at about two degrees, from the West Chamber, continuously through the Flint-knife and Reindeer Galleries, to the mouth of the Steep Slide Hole. Beyond the latter point to the north entrance they are not so well defined, but their dip is in the opposite direction, and amounts to four or five degrees. In the Pen Gallery the inclination is southwards—that is, from the West to the South Chamber.

Omitting the detrital accumulations in and immediately adjacent to the north and first and second west entrances, the dips of both the third and fourth beds corresponded, in amount and direction, to that of the grooves in the same branches of the cavern. But between the eastern end of the Flint-knife Gallery and the northern end of the Crystal Gorge the inclination of these beds was southwards—that is, from the former to the latter point.

In the Reindeer Gallery the stalagmitic floor dipped southwards, at an angle of 25°, from its northern end to a few feet beyond the Steep Slide Hole; thence to the eastern end of the Flint-knife Gallery its dip was reversed in direction and greatly diminished in amount; and from the latter point to the Crystal Gorge it again dipped southward, but still at a small angle. The exceptionally large inclination at the northern end was due to the fact that there the stalagmite covered the talus formed by the first bed, beneath which the second and third beds lay.

Deposits in the less important parts of the Cavern.—The description just given of the "Third" and "Fourth" Beds applies only to the West Chamber, the Flint-knife Gallery, and the northern branch of the Reindeer Gallery.

South of the Crystal Gorge the deposit was a mixture of loam, fine sand, and finely comminuted shale in variable proportions, occasionally cemented and stained with ferruginous matter. It was commonly disposed in distinct layers, which, instead of being horizontal, were parallel to the limestone walls, and therefore approximately vertical. The loam was much paler than the typical red cave-earth, and contained no stones.

Kelly's Gallery was filled to the roof with an accumulation having precisely the same characters, both positive and negative. In short in both these branches the materials were such as to suggest that they were perhaps introduced through small crevices or flues which possibly occur in the roof.

The Pen Gallery and Munday's Gallery contained third-bed materials only; the latter, however, was too narrow to be excavated at any great depth.

The deposit in the South Chamber, Keeping's Gallery, and King's Gallery was a mixture of such materials as composed the "third" and "fourth" beds.

Shells.—A considerable number of dead land-shells of existing species were found in the stalagmitic floor and under loose stones lying on the surface in that part of the Flint-knife Gallery where there was no stalagmite. A few were met with also in, and immediately beneath, the stalagmite itself. They were most numerous near the external entrances and under the cross fracture in the roof of the Flint-knife Gallery (Plate XLIII. *m*, fig. 2). A common limpet-shell was found on the surface of the third bed immediately beneath this roof-fracture, and was the only marine organism met with.

Mammalian Remains.—Bones were found in the stalagmite and in the first, third, and fourth beds. Their distribution is shown in the following Table:—

Table I.

Nos. affixed to each day's find.	Date when found.	Branches of the cavern where found.	Distances from the entrance of each gallery.	Beds.	Depths in the beds.	Thickness of over-lying detrital bed.	Thickness of over-lying stalagmite.	Distances from nearest external entrance.	Numbers of bones found in each locality.
	1858.		feet.		inches.	inches.	inches.	feet.	
1.	July 16.	Reindeer Gallery	15	First	18	0	0	15	12
2.	17.	„ „	19	„	18	0	6	19	10
3.	19.	„ „	19	Third	24	50	6	19	1
4.	20.	„ „	20	„	24	47	6	20	9
5.	„	„ „	23	„	21	37	6	23	1
6.	„	„ „	24	„	18	33	6	24	2
7.	21.	„ „	29	„	12	17	6	29	10
8.	22.	„ „	39	„	9	0	6	39	3
9.	23.	„ „	37	„	6	0	6	37	3
10.	„	„ „	32	„	6	0	6	32	1
11.	24.	„ „	47	„	9	0	8	47	2
12.	26.	„ „	47	„	10	0	8	47	4
13.	27.	„ „	76	„	6	0	3	76	6
14.	28.	„ „	70	„	2	0	4	70	52
15.	„	„ „	67	„	7	0	4	67	1
16.	29.	„ „	71	„	30	0	4	71	1
17.	30.	„ „	67	Stalagmite	...	0	4	67	1
18.	„	„ „	36	Third	36	0	6	36	1
19.	31.	„ „	71	„	30	0	4	71	10
20.	Aug. 2.	Flint-knife Gallery	2	„	0	0	3	56	25
21.	„	Reindeer Gallery	70	„	14	0	4	70	1
22.	„	Flint-knife Gallery	1	„	9	0	3	57	9
23.	„	Reindeer Gallery	69	„	28	0	4	69	4
24.	3.	„ „	68	„	33	0	4	68	30
25.	4.	Flint-knife Gallery	4	„	0	0	3	54	65
26.	„	„ „	3	„	6	0	3	55	11
27.	„	„ „	3	„	9	0	3	55	1
28.	5.	„ „	7	„	0	0	2	51	121

Table I. (continued).

Nos. affixed to each day's find.	Date when found.	Branches of the cavern where found.	Distances from the entrance of each gallery.	Beds.	Depths in the beds.	Thickness of overlying detrital bed.	Thickness of overlying stalagmite.	Distances from nearest external entrance.	Numbers of bones found in each locality.
	1858.		feet.		inches.	inches.	inches.	feet.	
29.	Aug. 6.	Flint-knife Gallery	10	Stalagmite	...	0	2	48	6
30.	„	„ „	11	Third	3	0	1	47	7
31.	„	„ „	7	„	16	0	2	51	4
32.	„	„ „	9	„	33	0	2	49	2
33.	7.	„ „	12	„	0	0	1	46	9
34.	„	„ „	12	„	9	0	1	46	2
35.	„	„ „	10	„	36	0	2	48	9
36.	9.	„ „	17	„	13	0	0	41	4
37.	„	„ „	19	„	28	0	0	39	5
38.	10.	„ „	23	„	4	0	0	35	18
39.	„	„ „	20	„	24	0	0	38	7
40.	11.	„ „	24	„	34	0	0	34	8
41.	12.	„ „	29	„	14	0	1	29	2
42.	„	„ „	26	„	33	0	0	32	6
43.	13.	„ „	40	„	0	0	0	18	2
44.	14.	„ „	34	„	58	0	0	24	12
45.	16.	„ „	36	„	60	0	0	22	2
46.	17.	„ „	49	„	30	0	0	9	2
47.	„	„ „	42	„	36	0	0	16	6
48.	„	„ „	42	„	42	0	0	16	9
49.	18.	„ „	26	„	42	0	0	32	1
50.	„	„ „	36	„	54	0	0	22	1
51.	19.	„ „	40	„	60	0	0	18	29
52.	20.	„ „	46	„	60	0	0	12	64
53.	„	„ „	49	„	36	0	0	9	1
54.	24.	West Chamber ...	10	„	48	0	0	0	44
55.	25.	„ „	3	„	48	0	0	5	1
56.	26.	„ „	4	„	63	0	0	4	13
57.	27.	„ „	4	„	60	0	0	4	40
58.	28.	„ „	4	„	96	0	0	4	5
59.	„	„ „	4	„	0	0	0	4	1
60.	31.	„ „	2	„	54	0	0	6	3
61.	Sept. 1.	„ „	4	„	60	0	0	4	14
62.	2.	„ „	3	„	57	0	0	5	16
63.	3.	„ „	8	„	84	0	0	2	15
64.	5.	„ „	6	„	108	0	0	4	30
65.	7.	Flint-knife Gallery	50	„	66	0	0	8	10
66.	9.	Pen Gallery	6	Stalagmite	...	0	0	...	1
67.	10.	South Chamber...	...	„	...	0	0	...	2
68.	13.	„ „	...	„	...	0	0	...	2
69.	14.	„ „	...	„	...	0	0	...	2
70.	15.	West Chamber ...	7	Third	48	0	0	3	6
71.	18.	South Chamber...	...	„	0	0	9	...	2
72.	23.	West Chamber ...	5	„	156	0	0	5	9
73.	24.	„ „	5	„	156	0	0	5	23
74.	25.	„ „	5	„	156	0	0	5	5
75.	28.	„ „	5	„	156	0	0	5	13
76.	29.	„ „	6	„	132	0	0	4	2
77.	30.	Flint-knife Gallery	40	„	96	0	0	18	2
78.	Oct. 1.	„ „	36	„	96	0	0	22	1
79.	6.	„ „	3	„	42	0	3	55	8
80.	11.	Reindeer Gallery	34	„	58	0	6	34	7
81.	12.	„ „	24	„	42	37	6	24	8
82.	13.	„ „	10	„	42	50	0	10	2
83.	„	„ „	16	„	42	60	0	16	3

TABLE I. (continued).

Nos. affixed to each day's find.	Date when found.	Branches of the cavern where found.	Distances from the entrance of each gallery.	Beds.	Depths in the beds.	Thickness of overlying detrital bed.	Thickness of overlying stalagmite.	Distances from nearest external entrance.	Numbers of bones found in each locality.
	1858.		feet.		inches.	inches.	inches.	feet.	
84.	Oct. 14.	Reindeer Gallery	26	Third	42	27	6	26	5
85.	16.	,, ,,	70	,,	0	0	4	70	1
86.	20.	,, ,,	34	Fourth	24	55	6	34	3
87.	22.	,, ,,	81	Stalagmite	...	0	8	81	2
88.	23.	,, ,,	82	Third	0	0	9	82	1
89.	25.	,, ,,	82	,,	58	0	9	82	4
90.	27.	,, ,,	83	,,	48	0	10	83	11
91.	28.	,, ,,	85	,,	36	0	12	85	12
92.	29.	,, ,,	86	,,	36	0	12	86	25
93.	Sept. 8.	Flint-knife Gallery	49	Fourth	6	66	0	9	1
94.	Oct. 9.	Reindeer Gallery	24	,,	6	80	6	24	1
95.	30.	,, ,,	81	Third	8	0	8	81	8
96.	Nov. 13.	West Chamber	6	,,	132	0	0	4	2
97.	18.	Reindeer Gallery	115	,,	0	0	0	115	425
98.	20.	,, ,,	114	,,	0	0	0	114	68
99.	26.	,, ,,	110	,,	0	0	0	110	26
102.	29.	,, ,,	3	First	36	0	0	3	1
103.	,,	,, ,,	10	,,	30	0	0	10	29
104.	,,	,, ,,	32	Stalagmite	0	0	6	32	7
105.	,,	,, ,,	34	Third	24	0	6	34	3
106.	,,	Flint-knife Gallery	5	,,	0	0	2	53	14
107.	,,	,, ,,	10	,,	0	...	2	48	11
108.	,,	,, ,,	14	,,	0	...	1	44	7
109.	,,	,, ,,	16	,,	0	...	1	42	7
110.	,,	,, ,,	22	,,	0	...	0	36	1
	1859.								
111.	Jan. 6.	Reindeer Gallery	28	,,	42	20	6	28	3
112.	14.	Steep Slide Hole	14	,,	33	...	0	40	3
113.	15.	Reindeer Gallery	20	,,	54	47	6	20	4
114.	20.	,, ,,	18	,,	48	53	6	18	4
115.	21.	,, ,,	15	,,	108	60	0	15	3
116.	Feb. 4.	West Chamber	7	,,	120	0	0	3	2
117.	6.	Flint-knife Gallery	14	Stalagmite	...	0	0	44	1
122.	Mar. 8.	South Chamber	...	Third	3	0	4	...	4
124.	10.	,, ,,	...	,,	24	0	4	...	1
125.	16.	,, ,,	...	,,	30	0	4	...	2
126.	18.	King's Gallery	...	,,	24	0	4	...	1
128.	28.	Keeping's Gallery	...	,,	30	0	3	...	1
130.	April 4.	Reindeer Gallery	50	,,	9	0	8	50	1
131.	6.	King's Gallery	7	,,	57	0	0	...	2
132.	20.	,, ,,	0	,,	9	0	0	...	1
135.	June 7.	Steep Slide Hole	28	,,	12	0	0	54	3
139.	21.	Reindeer Gallery	36	Fourth	120	48	6	36	2
141.	23.	West Chamber	0	Third	42	0	0	10	2
	1858.								
143.	Oct. 29.	Reindeer Gallery	74	Stalagmite	...	0	0	74	1

The number 100 and a few others, which are omitted in the first column, were appropriated to other objects of interest (chiefly "Flints"). The numbers given in the first column were written on the bones for the purpose of identification and reference. By "entrance" in fourth column is meant that end of the gallery by which it is entered proceeding directly in from the road or north entrance. Thus the junction of the Reindeer and Flint-knife Gallery is the "entrance" of the latter.

The substance of Table I. is given in a compendious form in Table II.

TABLE II.

Beds.	Steep Slide Hole.	Reindeer Gallery, North.	Reindeer Gallery, South.	Flint-knife Gallery.	West Chamber.	Pen Gallery.	South Chamber.	King's Gallery.	Keeping's Gallery.	Totals.
Stalagmite	......	11	......	7	......	1	6	......	......	25
First Bed	......	52	......	......	......	......	......	......	......	52
Third Bed	6	247	519	507	244	......	9	4	1	1537
Fourth Bed.........	......	6	......	1	......	......	......	......	......	7
Totals...............	6	316	519	515	244	1	15	4	1	1621

Of the bones connected with the stalagmitic floor, two deserve particular mention. At 67 feet from the North Entrance, and on the eastern side of the Reindeer Gallery, a fine bone, identified by Dr. FALCONER as the humerus of Bear, was found imbedded *within* the floor, which was beautifully white and stainless. It lay with its longest axis in the plane of the floor, and no trace or indication of it was discoverable from either the upper or the lower surface. On the same side of the gallery, a few feet further south, a little beyond the junction of the two chief galleries, lay a fine Reindeer antler. It was found lying *on* the stalagmite, firmly attached to but not imbedded in it; indeed some portions of it were completely free from more than the slightest incrustation (*antè*, p. 477).

From Table II. it is seen that the third was *the* ossiferous bed; it yielded 1537 of the 1621 bones found in the cavern—that is, 95 per cent. of the whole series. They were more abundant at the sides than in the middle of the galleries, and on the whole were larger and of darker colour in the lower part of the bed than in the upper. Occasionally some of those which were discoloured bore marks somewhat resembling such as are sometimes left by mosses on stones on which they have grown; whilst on some others were found the teeth-marks of the animals by which they had been gnawed.

In some parts of the two principal galleries the fossils were confined to an upper and lower band of the bed, which were separated by an intermediate layer of a very fine loam, usually about 9 inches thick, and destitute of stones as well as bones.

The distribution of the fossils, as to depth, in this bed is shown in Table III.

TABLE III.

Branches of the Cavern.	Depths in the Third Bed.														
	On the surface.	From 0 to 1 foot.	From 1 to 2 feet.	From 2 to 3 feet.	From 3 to 4 feet.	From 4 to 5 feet.	From 5 to 6 feet.	From 6 to 7 feet.	From 7 to 8 feet.	From 8 to 9 feet.	From 9 to 10 feet.	From 10to11 feet.	From 11to12 feet.	From 12to13 feet.	Totals.
Steep Slide Hole	...	3	...	3	...	...	...	...	...	...	...	...	...	...	6
Reindeer Gallery, North	2	91	17	83	43	8	...	...	...	3	...	...	...	...	247
Reindeer Gallery, South	519	...	...	...	...	...	...	...	...	...	...	...	...	...	519
Flint-knife Gallery	262	55	10	39	20	108	10	...	3	...	...	...	...	...	507
West Chamber	1	...	...	...	51	73	13	15	5	30	2	4	...	50	244
South Chamber............	2	4	1	2	...	...	...	...	...	...	...	...	...	...	9
Keeping's Gallery.........	...	...	...	1	...	...	...	...	...	...	...	...	...	...	1
King's Gallery	...	1	1	...	...	2	...	...	...	...	...	...	...	...	4
Totals........................	786	154	29	128	114	191	23	15	8	33	2	4	...	50	1537

Table III. presents the following prominent facts:—

(*a*) More than half of the fossils referred to the third bed were found lying on its surface; that is, either immediately beneath the stalagmite when this existed, or without any covering where it did not.

(*b*) All those found south of the Crystal Gorge lay on the surface. There was no stalagmite in this branch of the cavern.

(*c*) Excepting one only, no bones were met with either on the surface or in the uppermost 3 feet of the bed in the West Chamber.

(*d*) With the exception of one instance only, in which three small bones were found near the bottom of the "funnel-shaped pipe" between the North Entrance and the Steep Slide Hole, all the fossils which occupied depths exceeding 5 feet were met with in the West Chamber and the contiguous portion of the Flint-knife Gallery; in fact in the basin-shaped hollow (*d*, fig. 2, Plate XLIII.) formerly described.

The two last facts (*c* and *d*) show that in their arrangement the bones followed the contour of the lower rather than the upper surface of the bed; and thus support the suggestion already made, that the materials which rose above the normal level of the third bed were not really a portion of it.

The solitary bone found on the surface in the West Chamber had one of its ends cut off, apparently with some sharp instrument.

The fossils in the southern division of the Reindeer Gallery were the remains of young small rodents; they lay in three separate heaps, one of which contained as many as 425 bones, comprising probably the elements of complete skeletons.

Omitting these, the remaining 1112 specimens exhumed in other parts of the cavern were found in 124 localities, giving in whole numbers an average of nine for each locality. In a considerable number of cases, however, they were met with singly, whilst in a few others the numbers were large; and in one instance as many as 21 were lying together. Many of them were mere fragments, having no palæontological value. Bones representing distinct species of animals, and differing much in colour and other indications of exposure, occasionally lay confusedly together; whilst, with probably no more than one exception, those belonging to the same animal never were found lying in their true anatomical connexion*.

It appears from Table II. that, omitting the exceptional case of the south division of the Reindeer Gallery, the Flint-knife Gallery surpassed all other parts of the cavern in the number of bones it contained; but their different areas being considered, the West Chamber, the Flint-knife, and Reindeer Galleries yielded fossils in about the ratios of ten, five, and two respectively.

---

* The specimen referred to was the leg of a Bear. Mr. PENGELLY says, he had the entire mass (bones and loam) carefully extracted, and that immediately beneath were found subsequently several vertebræ and ribs of Cave-Bear (see *ante*, p. 478). On further examination Mr. BUSK found it necessary to introduce some corrections into the original statement (see Mr. BUSK's Report, p. 533).

Though very careful attention was given to the subject, nothing having the appearance of coprolites was found in the cavern.

Large quantities of the gravel were carefully examined, but, as is shown in Table II., very few fossils were found in it.

Human Industrial Remains.—Several pieces of flint (all more or less white and having a porcellanous aspect, and some of which at least are believed to be *human implements*) were met with in various parts of the cavern. Their exact situations are shown in Table IV.

TABLE IV.

Nos.	Date when found.	Branches of the cavern where found.	Distance from the entrance of each gallery.	Beds.	Depths in the beds.	Thickness of over-lying detrital bed.	Thickness of over-lying stalagmite.	Distances from nearest external entrance.	Numbers written on the flints*.
	1858.		feet.		inches.	inches.	inches.	feet.	
1.	July 29.	Reindeer Gallery	74	Third	9	0	3	74	3
2.	,, 29.	,, ,,	74	,,	9	0	3	74	143
3.	,, 30.	,, ,,	47	,,	24	0	8	47	5
4.	,, 30.	,, ,,	37	,,	24	0	6	37	8
5.	Aug. 9.	Flint-knife Gallery	19	,,	10	0	0	39	2
6.	,, 12.	,, ,,	27	,,	36	0	0	31	4
7.	,, 17.	,, ,,	42	,,	42	0	0	16	7
8.	Sept. 9.	Pen Gallery	14	,,	42	0	9	22	6
9.	,, 24.	West Chamber	8	,,	84	0	0	2	9
10.	,, 29.	,, ,,	6	,,	132	0	0	4	1
11.	,, 30.	,, ,,	3	Fourth	6	90	0	7	10
12.	Oct. 12.	Reindeer Gallery	35	Third	33	0	6	35	11
13.	,, 14.	,, ,,	26	,,	48	27	6	26	84
14.	,, 29.	,, ,,	86	,,	36	0	12	86	
	1859.								
15.	Jan. 20.	,, ,,	18	,,	48	53	6	18	114
16.	,, 20.	,, ,,	18	,,	48	53	6	18	114
17.	,, 21.	,, ,,	15	,,	108	60	0	15	115
18.	Feb. 4.	West Chamber.	7	,,	120	0	0	3	116
19.	,, 10.	Flint-knife Gallery	34	Fourth	16	57	0	24	118
20.	,, 10.	,, ,,	34	,,	16	57	0	24	118
21.	,, 12.	West Chamber	5	,,	12	156	0	5	119
22.	,, 12.	,, ,,	5	,,	12	156	0	5	119
23.	,, 19.	,, ,,	5	,,	24	156	0	5	120
24.	,, 19.	,, ,,	5	,,	24	156	0	5	120
25.	,, 20.	,, ,,	5	,,	24	156	0	5	121
26.	,, 20.	,, ,,	5	,,	24	156	0	5	121
27.	Mar. 24.	Keeping's Gallery	36	Third	36	0	3	...	127
28.	,, 30.	,, ,,	40	,,	48	0	3	...	129
29.	May 26.	West Chamber	5	Fourth	108	156	0	5	133
30.	June 11.	Reindeer Gallery	33	,,	126	51	6	33	136
31.	,, 16.	,, ,,	31	,,	144	58	6	31	137
32.	,, 16.	,, ,,	31	,,	144	58	6	31	137
33.	,, 18.	,, ,,	34	,,	120	48	6	34	138
34.	,, 23.	,, ,,	20	,,	144	96	6	20	140
35.	,, 23.	,, ,,	20	,,	144	96	6	20	140
36.	,, 23.	,, ,,	20	,,	144	96	6	20	140

* The numbers from 114 upwards correspond with those in the "Daily Register."

The flints are numbered in the first column in the order of the dates of their discovery. Numbers differing from these were written on all of them excepting the fourteenth when they were from time to time forwarded to Dr. Falconer. In order to guard against confusion, these are entered also in the Table, and will be found in the last column. The former numbers only will be used here.

No. 2 flint was accidentally broken and found to be whitened throughout. Find Nos. 6 and 8 were discovered by Dr. Falconer to be portions of one implement (see Mr. Evans's Report, p. 549). No. 17 was found with three bones near the bottom of the funnel-shaped cavity ("*c*," Plate XLIII. fig. 1).

The following summary of Table IV. shows the distribution of the flints:—

Table V.

Beds.	Reindeer Gallery.	Flint-knife Gallery.	West Chamber.	Pen Gallery.	Keeping's Gallery.	Totals.
Third	10	3	4	1	2	20
Fourth ...	7	2	7	0	0	16
Totals......	17	5	11	1	2	36

From the foregoing Tables we arrive at the following results:—

(*a*) In relation to its area the West Chamber was the richest part of the cavern in the "Flint Implements" as well as in bones.

(*b*) No flints were found in the first bed or the stalagmite, whilst bones were found in both.

(*c*) As in the case of the bones, no flints occurred in the so-called upper portion of the third bed, which, in the West Chamber and the adjacent part of the Flint-knife Gallery, filled the cavern to the roof.

(*d*) In the three principal branches of the cavern the third bed yielded 17 flints and 998 bones. Two of the former, or about 12 per cent., were 9 inches deep in the bed, whilst the remainder were at lower levels. Of the latter, on the contrary, as many as 372, or 37 per cent., were above the level of the highest flint, and were covered by the overlying stalagmite, in which were found remains of the Cave-Bear and Reindeer.

(*e*) Of the 1621 bones and 36 flints found in the cavern, seven of the former and sixteen of the latter were met with in the fourth or gravel bed; or, putting each total =1000, and equating to this, the bones in the gravel are to the flints in the same deposits in the ratio of 4 to 444, or as 1 to 111. Taken as wholes, therefore, the "implement" zone is lower than that of the bones.

Note.—This report and that of Mr. Bristow were received a considerable time before the others had been written.

IV. Mr. Bristow's *Notes on his Survey of the Cave.*

After describing the locality and stating that certain lines on the plan represent the floor of the cave as it existed at the time of his visit (*i. e.* after the removal of the bone-bed and part of the shingle bed), and other lines the top and bottom of the bone-bed and of the top of the stalagmite floor, Mr. Bristow proceeds to say that the "longitudinal sections through the two principal Galleries (Reindeer Gallery and the Flint-knife Gallery, Plate XLIII. figs. 1 & 2) afford a good idea of the general arrangement of the contents of the cave, while the cross sections (A to H) serve to show, in addition, the peculiar shapes into which the galleries have been worn out of the rock.

"The lower part of the cave, from the base of the bone-bed to the floor, and to as great a depth as any explorations have been extended, consists of a reddish-brown clay or loam, containing rounded pebbles of quartz, rounded fragments of the slate rocks of the district, &c., precisely similar in character and appearance to those forming the raised beaches visible on the neighbouring coast, as well as to the shingle on the shore of Mudstone sands, north of Brixham.

"Immediately overlying the pebble bed is the deposit in which numerous bones have been discovered, and which has in consequence received the name of 'the bone-bed.'

"It may be divided into three divisions:—

"The lower part, in which the supposed flint knives were met with, and also the greater portion of the bones which have been found, is a ferruginous brown-coloured loam or clay with included angular fragments of limestone, some of which are of considerable dimensions.

"There is no appearance of any symmetrical arrangement of the materials forming this bed, both the upper and the under surfaces of which are very uneven and irregular, forming undulations and filling up hollows or depressions in the upper part of the subjacent pebble bed.

"For some distance from the entrance (33 or 34 feet) a dark-coloured deposit rests upon the bed just noticed; it is composed of small angular fragments of limestone, with a white powder imbedded in a brown loamy base. From the circumstance of its being darkly stained with carbonaceous matter (apparently), the name 'Charcoal-bed' has been conferred upon it; its thickness is very variable.

"An accumulation called the 'white angular limestone,' in consequence of its being made up of broken angular fragments of limestone imbedded in a white mortar-like cement, rests immediately upon the charcoal-bed, and forms the upper part of the deposit containing the bones.

"When the cave was first discovered its present entrance was concealed by a rubbly talus of limestone, which formed a conglomerate in places, and covered the true bone-beds, as is shown at the northern end of the longitudinal section (Plate XLIII. fig. 1).

"For about the first 19 feet from the entrance the rock forming the roof was divided by a fissure, the space being filled up with a mass of rubbly limestone, similar to that already described as blocking up the mouth of the cave.

"From this point southwards the roof was more or less covered with stalactitic carbonate of lime, which is still in the course of formation.

"The charcoal-bed, as well as the 'white angular limestone,' are described as terminating somewhat abruptly near a cross joint in the limestone, between 34 or 35 feet from the entrance.

"Between the place where the charcoal-bed ends and the principal gallery westward (the Flint-knife Gallery) commences, the extreme width of the cave from side to side is 8 feet, and its greatest height from the floor 14 feet; the roof also tapers gradually to a pointed ridge, and its height is reduced to 10 feet 6 inches by the formation of stalagmite, which at a short distance from cross section D increases considerably in amount.

"Cross section D shows the peculiar form of the passages in the Reindeer, Flint-knife, and Pen Galleries. From it, and from cross sections E, F, and G, it will be perceived that the limestone has been most eroded, and that the cave assumes a peculiar elliptical form and is of the greatest width, at the part which is filled with the bone-bed.

"Four feet north of cross section D the stalagmite covering the bone-bed first makes its appearance, and extends with a slightly variable thickness as far as the Flint-knife Gallery, along the south side of which it continued for 9 feet, terminating in a minor transverse hollow worn into the limestone.

"On the north side of the Flint-knife Gallery it extended nearly to the wall of the gallery for the same distance as on the south side, without, however, actually coming in contact with it.

"Hence, onwards, in a southerly direction the passages become much contracted, and the space between the walls of the cave was, on its first discovery, almost entirely choked by a deposit of stalagmite. On the removal of this, with much labour, the explorations were continued for an additional 50 feet southwards; and small bones of recent date were found lying on the surface of the bone-bed, which at this distance falls rapidly and lies at a much lower level than it does in either of the passages already described.

"Throughout the entire length of the Flint-knife Gallery the rock forming its side has been considerably eroded, being worn into shapes somewhat resembling short broad stalactites, while the roof is smoothly arched and free from calcareous incrustation. The western extremity of the gallery is 1·21 foot higher than the eastern end, and 7·3 feet lower than the present entrance to the cave.

"At 36 feet the bone-bed rises to the roof, and for the rest of the distance towards the West Chamber it occupies the entire passage. In the West Chamber itself, the bottom of the bone-bed fills a depression or hollow in the pebble bed, extending to the floor of the cave, on a level with which bones were found and also a flint knife.

"The passage named 'Pen,' as well as the 'South Chamber,' became much contracted both in height and width; and branching off from the latter are minor hollow spaces, apparently eroded between the planes of cleavage."

V. *Notes on the Specimens of the Cave-beds.*

Together with the animal remains, a collection was made of sixty-nine lithological specimens to illustrate the character of the several deposits in the Cave, and which are numbered in the "Register" I. to LXIX. At the request of the Committee I examined and described these specimens. I do not consider it necessary to give all the details of that description here, as it would involve a repetition of much that Mr. Pengelly and Mr. Bristow have described. I will confine myself, therefore, to a short abstract and summary.

Stalagmite, Nos. I.–VII., XIV.–XXV., XXX., LXVI.–LXVIII.—6 to 12 inches thick, and white or red. Limestone breccia attached to under surface of some specimens. Masses of red and white calcareous spar with some fragments of limestone from the Crystal Gorge. Mixed with the calcareous spar are seams of stalagmite. Thin plates ($\frac{1}{4}$ to $\frac{1}{2}$ inch) of red earthy stalagmite and calcareous concretions interstratified with the Cave-earth (I., II., III., XLV.).

First Bed—Limestone Breccia, Nos. XXVI., XXXIII.–IV., L., LXV., LXIX.—Angular fragments of fallen limestone of various sizes cemented by carbonate of lime, at times crystalline, at others white and earthy. An occasional fragment of bone. In some specimens from the South Chamber (LXV.) the calc-spar, which has not filled up all the interstices between the limestone fragments, assumes nullipore-like forms.

Second or black Bed, No. LV.—Peaty calcareous earth (or leaf-mould?) with angular fragments of limestone.

Third Bed—Cave-earth, Nos. XL., XLI., XLIII., XLVII.–VIII., LII., LIV., LIX., LXII.—Reddish loam, or loamy clay, with angular fragments of the limestone fallen from the roof, some of a large size. No. XL. shows that it extends to just outside the second West Entrance. No. LIX., "found in the third bed in various places," consists of pebbles the same as those composing the shingle bed beneath, with small worn pieces of quartz and minute crystals of iron-pyrites (Pengelly), nodules of brown hematite, and pieces of cellular calc-spar coated and interspersed with the peroxide of iron. Fragments of old stalagmite (Nos. VIII. to XIII.) from the West Chamber and Flint-knife Gallery, with rounded gravel attached to the under surface of three specimens.

Fourth or Shingle bed, Nos. XXVII., XXXI.–II., XXXVI.–IX., XLII., XLVI., XLIX., LVI., LVII., LXIII.—Pebbles of clay-slate, micaceous and chloritic schist, quartz, limestone, siliceous sandstone, red micaceous sandstone, greenstone, and red porphyry, with some peculiar round red calcareous concretions full of bits of white schist, a few subangular pieces of quartz and of flints, and occasional angular fragments of limestone,—all generally in a base of reddish loam, but occasionally of sand. In places the shingle forms a red calcareous conglomerate; in others it contains innumerable very small flat fragments of schist. The base of the bed (XXXI. & XLVI., Flint-knife and Reindeer Gallery) is occasionally cemented by the oxide of iron or of manganese. In the West Chamber a few angular fragments of limestone are mixed with the shingle. No. XXXIX. was, like XL., found just outside the second West Entrance.

VI. Mr. Busk's *Report on the Animal Remains.*

Part I.—List of the Sites in which the Remains were found, and the enumeration of the various specimens which occurred in each.

The Roman numerals in the first column are those affixed to each specimen, and corresponding with those in Mr. Pengelly's "Register" (Arabic numerals), where the exact site of each "find" is described. In the second column are given the number of individual specimens in each "find" (see Table I. p. 489).

The letters H. F. indicate that the determination is on the authority of Dr. Falconer, as taken from his notes; they are applied either to specimens which have not come under my notice or which I have not identified, or to those with respect to which I have ventured to differ from him.

The situation in the Cavern of each site will be seen by reference to the corresponding number in Part II.

I.	12.	Carnassial tooth of *Canis vulpes*; ten incisor teeth of Rabbits and smaller rodents; femur of *Arvicola amphibius*?
II.	10.	Fragment of the shaft of right radius of a small ruminant (sheep or goat); a proximal phalanx of same species; numerous small Birds' and Rabbits' bones: all these specimens have a recent look, though dry and fragile.
III.	1.	Gnawed fragment of a large long bone of coarse texture; tibia of *Rhinoceros*?
IV.	9.	A canine tooth and a much-gnawed lumbar vertebra of *Ursus*; two much-gnawed fragments of the tibia of *Equus*; lower end of right tibia and what appears to be a portion of the palmate horn of *Cervus tarandus*—the latter has an incision (H. F.)? or sharp indentation on one edge; gnawed fragment of tibia of *Rhinoceros*?; fragment and base of mandible of *Hyæna*, and several undeterminable splinters of long bones, one very thick and heavy.
V.	1.	Fragment of astragalus of *C. tarandus*.
VI.	2.	Upper part of sacrum of *Hyæna*; fragment of lower molar of *Rhinoceros*.
VII.	10.	Young horn base of *Capreolus*?; much-worn upper milk-molar of *C. tarandus*; lower canine of *Hyæna*, $6''{\cdot}2 \times 5''{\cdot}4$; much gnawed fragment of radius of young *Equus*; gnawed splinter of inferior border of right scapula of *Rhinoceros*; part of nasal bone of *Rhinoceros*?; fragment of the upper end of the left radius of *Ursus*?, of a very dark colour and heavy; gnawed splinters of long bone, not certainly determinable, but probably of *Rhinoceros*.
VIII.	3.	Metatarsal of *Hyæna*; fragments of radius and of a rib of *Ursus*.
IX.	3.	Two bones of Bird; extremity of rib of *Ursus*.
X.	1.	Portion of shaft of femur of young or small *C. tarandus*.
XI.	3.	Two fragments of base of horn of *C. elaphus*; fragment of long bone of *Bos*?
XII.	4.	Gnawed fragment of femur of *Rhinoceros*; small gnawed and apparently rolled splinters of cannonbone and tibia of *Bos*; fragment of scapula of ——?
XIII.	6.	Gnawed fragment of scapula of *Rhinoceros*; proximal phalanx of *Ursus* of small size; right metatarsal and fragment of pelvis of *Capreolus*, both in the same light porous condition; proximal phalanx and splinter of long bone of *C. tarandus*.
XIV.	52.	Forty-four bones of young Hare and Rabbit? in beautiful preservation; four bones of small Birds; enamel cap of lower canine of *Ursus*; canine tooth of *Vulpes*; proximal phalanx and portion of calcaneum of *Capreolus*.
XV.	1.	Left calcaneum of *C. tarandus*.
XVI.	1.	Right lower canine. *Ursus*.
XVII.	1.	Perfect right humerus of *Ursus* of the smaller size, imbedded in white chalky matrix, and covered in part with red crystalline stalagmite.
XVIII.	1.	Large much-worn upper canine of the larger form of *Ursus* (*U. spelæus*, H. F.).
XIX.	10.	Right unciform, two metacarpals or metatarsals, a proximal phalanx, the right lower canine, the right penultimate upper molar, and a fragment of the cranium of *Ursus*; gnawed fragment of left radius of *C. tarandus*; the right upper canine and the calcaneum of *Hyæna*; much-gnawed fragment of left ulna of *Rhinoceros*. N.B. All these specimens are dark-coloured and heavy.
XX.	25.	Bones of young and older Hares, light and porous.

XXI.	1.	Right lower canine and two phalanges of large *Ursus*.
XXII.	9.	Much-gnawed lower end of radius of *Bos*; lower two thirds of humerus of *Equus*; shaft of humerus, right lower canine, and very young or fœtal tibia of *Ursus*; one trochlea of cannonbone of *C. tarandus*; much-gnawed fragment of bone of *Rhinoceros*?; left hind proximal phalanx of *Capreolus*; other fragments undeterminable.
XXIII.	4.	Three fragments of metacarpals or metatarsals of *Ursus*; an amorphous gnawed fragment.
XXIV.	30.	All bones of one and the same *Ursus*, of large size, and comprising:— 1. A nearly entire sacrum. 2. 3. } Portions of right and left *ossa innominata*, including the *acetabula*. 4. A portion, about 9″ long, of the right femur, wanting the head. 5. Portion, between 6″ and 7″ long, of the right tibia. 6. Fragment of the right scapula, including the entire glenoid fossa. 7. Upper part (nearly half) of the left ulna. (Corresponding in size with SCHMERLING's second or most common form.) 8. Lower end of left radius, with the articular surface nearly entire. 9–18. Vertebræ, or portions of vertebræ. 19–23. Portions of various ribs, on one of which is a small notch, such as might be made by means of a flint or stone implement (H. F.). 24–30. Fragments of various bones, and an entire scapho-lunar bone. N.B. All these bones are of a light yellowish colour, friable, and porous. The cancellated tissue not at all infiltrated, but open and of a reddish colour. Among the small bones is a fragment apparently of the metacarpal or metatarsal of *Hyæna*.
XXV.	65.	A numerous collection of bones, chiefly if not entirely of young Hares, Rabbits, and Birds, with small fragments of angular bone, breccia, one containing a premolar in germ of *Ursus*, dendritic.
XXVI.	11.	Right ramus of mandible of young *Ursus*, with the canine just emerging (the crown of the penultimate molar is just extruded); right and left ultimate lower molars with fangs still in germ, all probably belonging to the same animal (considered *Ursus arctos* by H. F.); a portion of the right maxilla with the 4 pm of very large size *in situ*; five other very young teeth, all probably of the same individual; ungual phalanx, black, of *Ursus* (mature); the lower milk-canine of *Ursus*?; and a much rolled fragment of the mandible of *Hyæna*. N.B. The last two specimens are dark-coloured and heavy, and in quite a different condition from those belonging to the *Ursus*, which, except the ungual phalanx, are light-coloured and much fresher looking.
XXVII.	1.	The enamel cap of canine tooth of *Ursus*, clearly the fellow to one of those in No. XXVI.
XXVIII.	121.	Numerous bones of small rodents, including *Arvicola*, &c.; young Hares and Rabbits, &c., with the teeth; the entire left metacarpal of *Capreolus*; the right upper canine of *Hyæna*, dark-coloured and heavy, and in very different condition from the other remains.
XXIX.	6.	Left ramus of mandible of young *Ursus*, forming a pair with that recorded in No. XXVI. It contains the second incisor fully protruded, the third just appearing in the alveolus, the milk-canine still *in situ*, the base of the first premolar broken off, and the third and fourth premolars fully protruded, though quite unworn. It is to be remarked that these two portions of the same mandible, of most fragile consistence and yet quite uninjured (except perhaps at the time they were extracted), were found in the Flint-knife Gallery, one 3 feet from the entrance and 6 inches deep in the third bed, and the other 10 feet from the entrance and lying *on* the stalagmite floor. The only other bone belonging to *Ursus* was the shaft of a very young tibia, doubtless of the same animal, and which was found sticking in the stalagmite. The left metatarsal of *C. tarandus*; a long bone and the vertebra of young Hare imbedded in hard red stalagmite. N.B. Though six specimens are recorded in the Register, only five could be found.
XXX.	7.	Three enamel caps of canines and one of the outer incisor, and the fragment of the metacarpal of a very young *Ursus*; the perfect metacarpal and the calcaneum of a mature *Ursus*; two bone-splinters; portion of the astragalus of *C. tarandus*. N.B. Probably the extra specimen belongs to No. XXIX.
XXXI.	4.	Much-worn upper right canine and fifth proximal phalanx of *Felis spelæa*; portion of sacrum and proximal phalanx of *C. tarandus*; a metacarpal or metatarsal and a portion of the third right rib of *Ursus*? N.B. Six specimens were found, though only four are noticed in the Register.
XXXII.	2.	Lower half of right humerus, of large size, of *C. tarandus*, gnawed; metatarsal of large *Bos* (very like some of those figured by Buckland, H. F.).

XXXIII.	9.	Bones of Hare, Rabbit, and Bird, some of them gnawed by *Arvicola*.
XXXIV.	2.	Outer incisor and upper canine of *Ursus*.
XXXV.	9.	Shaft of femur and gnawed fragment of bone of young *Ursus*; right calcaneum and base of metacarpal of large *Ursus*; proximal phalanx of *Equus*, corresponding in size with, though differing somewhat in colour from, a second phalanx recorded in No. LII.—both belonging to a horse about 15 hands high; the gnawed fragment of a rib of a large ruminant?; gnawed splinter of a long bone, probably cervine, and the proximal phalanx of *C. tarandus*?; fragment of a fœtal or very young bone; large gnawed splinter of radius of large ruminant.
XXXVI.	4.	Lower half of left humerus of *C. tarandus*, superficially gnawed as if by a Dog or Fox; gnawed fragment, humerus (?) of *Rhinoceros*; upper canine of the long and slender form (*vide* XCI.), and the antepenultimate lower molar ($\overline{4\ \text{pm}}$), also very narrow, of *Ursus*.
XXXVII.	5.	Three fragments of the sixth cervical vertebra of *Bos*, of small size; the penultimate upper molar ($\underline{2\ \text{m}}$) of *Bos*; a large metacarpal of *Ursus*, exactly like that recorded in No. XLII. N.B. The molar tooth of *Bos* here noticed is dark-coloured and heavy, of large size, whilst the vertebra is light, porous, and that of an animal probably of the size of the domestic Ox, of medium or small stature.
XXXVIII.	18.	The right metatarsal (entire) of *Capreolus*, 8″·3 long; the shaft of femur of *Capreolus*?; lower end of metacarpal of *C. tarandus*; numerous broken bones of Hares, Rabbits, Birds, &c. imbedded in angular breccia; gnawed fragment of radius of *Rhinoceros*; portion of shaft of very young femur of *Ursus*.
XXXIX.	7.	Lower third and the lower half of the right tibia of *C. tarandus*, very dark-coloured on the exterior, greyish within; the point of an antler of *Cervus elaphus*?, and a much-gnawed fragment of large coarse bone, probably *Rhinoceros*; proximal phalanx of *Felis spelæa* (*Hyæna*, H. F.); a metatarsal and a fragment of the ischium of *Ursus*.
XL.	8.	A much-worn upper third molar of *Bos*; portion of ilium and much-gnawed fragment of scapula of *Ursus*; fragment of left ischium, with part of acetabulum, and fragment of pubis of *Equus*; gnawed remnant of lower end of humerus of *Cervus* or *Bos* (*Ursus*, H. F.); gnawed, or much-weathered remnant, 6″·6 long, of horn of *C. tarandus*, with brow- and second antlers; two portions of humerus of *C. vulpes*, probably the same animal as in No. LXV.
XLI.	2.	Right upper canine of *Ursus*, large size, but quite unworn; the sacrum of a Bird.
XLII.	6.	Metatarsal or metacarpal of large size, a fragment of the ulna and of the radius, and the proximal end of a metatarsal or metacarpal of *Ursus*; the fourth left metatarsal of *Equus*; a small fragment of a long bone, probably of *Ursus*?
XLIII.	2.	Left upper canine of *Ursus* of small size, much weathered and cracked; incisor of Rabbit? N.B. In the Register two specimens are noted under this number, one being a small *skull*; but the above are the only specimens forthcoming, and I find in Dr. FALCONER's notes that he was only able to find the canine tooth.
XLIV.	12.	Left ramus of mandible (mature), but with the teeth unworn, and with the sockets of two small premolars immediately behind the canine and close together, and with the $\overline{4\ \text{pm}}$ and $\overline{2\ \text{m}}$ *in situ*, two right upper third molars, a portion of a metatarsal, the olecranon, a fragment of an immature ulna of *Ursus*; a nearly complete ulna, a worn fragment of the palmate horn, a proximal phalanx (split), and large part of the atlas of *C. tarandus*; the glenoid fossa of *Equus*.
XLV.	2.	Fifth left metatarsal of *Ursus*, like No. XXXVII. (metacarpal, H. F.); a splinter of tibia of large *Bos* (*B. primigenius*?).
XLVI.	2.	Much-gnawed shaft with small remnants of articular ends of metacarpal of *Equus*; fragment of humerus (*Ursus*, H. F.).
XLVII.	6.	Extremity of left mandible of *Ursus*, with the canine *in situ*, and immediately behind it two premolars close together, the anterior much the larger! (*vide* No. XLIV.); a portion of a cylindrical antler and fragment of a small tine of *Cervus*?; large, gnawed fragment of tibia of *Bos*?; fragment of pelvis and ulna, and the left parietal bone of *Ursus*, 4″·2 long and nearly entire, corresponding pretty closely with that of *U. arctos* in R. C. S. Museum (Horse, H. F.).
XLVIII.	9.	The entire crown of an unworn right upper canine, the antepenultimate lower molar ($\overline{4\ \text{pm}}$), a very much-worn lower canine of the middle size, and a fragment of the radius of young *Ursus*; the lower end of the right tibia of *Capreolus*, gnawed at the broken end, and corresponding in character with the specimen noticed under No. XIV.; a much-gnawed fragment of large bone, probably tibia of *Bos*; a proximal phalanx of *Hyæna*.

XLIX.	1.	Greater part of the right mandible of *Ursus*, with canine and penultimate molar *in situ* (two premolar sockets close to canine). N.B. It seems doubtful whether the canine, which is of the long slender type, really belongs to the jaw.
L.	1.	Left upper canine, very much worn, of *Hyæna*; corresponds with that in No. XXXI.
LI.	29.	Eight portions of bones belonging to *Ursus*, viz.:— 1. Portion of a long bone? 2. } metacarpals. 3. } 4. Ungual phalanx. 5. Lower end of radius. 6. Great part of left humerus. 7. Left condyle of lower jaw. 8. Two portions of a rib (gnawed), and besides these are what appears to be a fœtal or very young tibia of *Ursus*; gnawed fragment of pelvis, the calcaneum, proximal phalanx; large gnawed fragment of right side of pelvis, with the acetabulum entire, nearly the whole of the ilium, and the distal end of the right tibia of *C. tarandus*; a portion of the shaft of humerus and a portion of the shaft of the femur of corresponding dimensions of *Rhinoceros*; numerous fragments and splinters of ribs of small *Ursus*, &c.; the third upper molar of *Bos* (*vide* No. XXXVII.).
LII.	64.	Thirty or forty bones and teeth of a young *Ursus*, doubtless all belonging to the same animal; the gnawed fragment of a scapula, ribs, astragalus, metacarpals, a sternal bone, and bones and teeth of a mature *Ursus*; upper canine of *Felis spelæa*, much worn and exactly resembling that figured in 'Reliquiæ Diluvianæ,' pl. 22. figs. 6, 7; the atlas and fourteenth dorsal vertebra, and probably fragments of other bones of *C. tarandus*; fragments of metatarsal or metacarpal and the right lower canine of *Hyæna*; the anterior lower milk-molar of *Rhinoceros tichorhinus*; three fragments of the seventh cervical vertebra of *Rhinoceros*; several gnawed fragments. N.B. Three upper molars of the young Bear set in plaster; cannot be distinguished from the corresponding teeth of a young *Ursus arctos*.
LIII.	1.	Metatarsal of *C. tarandus*.
LIV.	44.	Bones of Rabbits; the tibiæ of the latter appear to be unusually long.
LV.	1.	Proximal end of radius of *C. tarandus*.
LVI.	13?	The left tibia, scapho-cuboid, astragalus, fragment of cannonbone of *C. tarandus*; two fragments of tibia of large *Bos*, most likely *B. primigenius*; six separate teeth and a considerable part of the left ramus of the mandible, containing second and third premolars and the carnassial tooth, of *Hyæna*. The third premolar in the latter specimen is split vertically, and the entire specimen bears a striking resemblance to that figured in Cuvier's 'Ossem. Fossiles,' pl. 194. fig. 1, from Gailenreuth; portion of right maxilla of *Felis spelæa*, and with first and second premolars *in situ* (3 pm and 4 pm);—this specimen appears to pair with that in No. LXI.; the left second premolar of *Rhinoceros* in germ, but of very large size; portion of tibia of *Ursus*, of large size; gnawed fragment of *Rhinoceros*. N.B. Thirteen specimens only are noted in the "Register," but there are at least sixteen with No. LVI. upon them.
LVII.	40.	All bones of apparently a very young *Ursus*.
LVIII.	5.	Five teeth of *Ursus* of different ages.
LIX.	1.	Seventh or eighth right rib of Sheep, sawn across at the distal end, and superficially gnawed by *Arvicola*: a recent bone.
LX.	3.	Outer incisor of *Ursus*, very dendritic; a small fragment of a flat rib of ——?; an amorphous fragment of bone, probably palate of *Ursus*.
LXI.	14.	Portion of left maxilla, with premolar *in situ*, and anterior part of same maxilla, with the external incisor *in situ*, of *Felis spelæa*; portion of shaft of femur, of radius, &c., probably feline; a third metatarsal of *Ursus*; a lower molar of *Rhinoceros*, unworn; another apparently milk-molar, of smaller size and irregularly worn, with a bevelled edge, of probably the same animal; several gnawed fragments of bones.
LXII.	16.	A water-worn cylindrical base of shed horn of large *Cervus*, with the burr nearly worn off (the brow-antler springs about 2 inches above the base: the circumference immediately above the burr is 7″·7); an entire right radius of *Equus*, 12″·5 long; fragment of radius, a large portion of the shaft of left humerus, the proximal end of the left ulna, a fragment of the shaft of femur, and a fragment of the right upper canine of *Ursus*; a portion of the scapula, including great part of the glenoid fossa and the commencement of the spine, of *Bos*; left upper carnassial tooth (1 m. s.) and the capital epiphysis of femur and carnassial tooth of *Hyæna* (cf.

		No. LXXIII.); a much-worn upper molar, quite black and very fragile, an astragalus (finely gnawed, H. F.), the left lower milk-molar, a good deal worn and of the same black colour as the upper molar and astragalus, and a large lower molar, much and unevenly worn, of *Rhinoceros tichorhinus*; the much-gnawed distal extremity of a cannonbone of *C. tarandus*; an amorphous fragment.
LXIII.	15.	Three teeth, gnawed fragment of metacarpal or metatarsal, and the os unciforme of *Ursus*; the left upper and lower canines and the third lower premolar of *Hyæna*; an upper right molar, a lower milk-molar, and a very large lower molar of *Rhinoceros tichorhinus*; a third upper molar and gnawed splinter of humerus of *Bos*; the calcaneum of *C. tarandus*. N.B. In the "Register" 15 specimens are mentioned under No. LXIII., of which 11 are teeth. Ten only are given above; and in Dr. FALCONER's notes only 10 are noted, and amongst them a lower molar of *Bos*, which is not now apparently forthcoming.
LXIV.	30.	Four or five bones of *C. tarandus*, including distal end of tibia, fragment of acetabulum?, fragment of metatarsal; the anterior part of right mandible, including the canine and two anterior premolars (considerably worn and of a dark colour), the distal end of the left tibia (apparently splintered and repaired during life), portion of pelvis with part of acetabulum, canine, right upper carnassial, a metacarpal or metatarsal bone of *Hyæna*; portion of right ischium and of a rib?, gnawed fragment of maxilla of a very old animal, retaining the stump of the penultimate molar worn down to the base and of a very dark colour, the left lower canine, the external incisor (*Hyæna*, H. F.), gnawed fragment of metacarpal, a proximal phalanx (*Hyæna*, H. F.), left half of atlas (*Hyæna*, H. F.), left upper canine, and a sternal bone of *Ursus*; an irregular weathered and rolled fragment of spongy bone, perhaps cranium of *Rhinoceros* or *Elephas*?, 1″·5 thick; right upper milk-molar, considerably worn, and left anterior upper molar, but little worn, of *Rhinoceros*; several gnawed fragments of bones.
LXV.	10.	Several portions of ribs of *Ursus*; gnawed fragment of lower end of right humerus of large *Ursus* (cf. No. LI.); fragment of a metacarpal or metatarsal of *Hyæna*; lower end of tibia and of radius of *Vulpes* (*vide* XL.). N.B. All these specimens of a very dark colour, hard and resonant.
LXVI.	1.	Much-worn upper right carnassial tooth of *Felis spelæa*, 1″·5 × 0″·75.
LXVII.	4.	Radius and ulna of *Ursus*; a very dark-coloured femur of young *Ursus* imbedded in a white chalky matrix; an amorphous fragment. N.B. The "Register" mentions only two specimens.
LXVIII.	2.	Portion of left maxilla with first and second molars, quite unworn and of very large size for *C. elaphus*, in situ; a broken molar, probably of the same animal.
LXIX.	2.	Two amorphous splinters of long bone, probably *Elephas*.
LXX.	6.	Distal end of right metacarpal of *C. tarandus*, much gnawed; two fragments of small ulna of *Ursus*; gnawed head of tibia, and an incisor (H. F.) of *Hyæna*; an amorphous fragment.
LXXI.	2.	Two portions of pelvis of *Rhinoceros*, including a considerable part of the ilium and the entire acetabulum, 4″·5 in diameter.
LXXII.	9.	Right astragalus, much gnawed, especially on the anterior, inner, and posterior sides, the distal end of the corresponding tibia, also gnawed on the same three sides, two other portions of the same tibia, of *Elephas primigenius*; a lower molar and right upper milk-molar in beautiful preservation, though slightly worn, of *Rhinoceros*; detached proximal epiphyses of tibia of *C. tarandus*; a fragment of scapula of *Bos*?; gnawed fragment of the base of horn of large *Cervus elaphus*?
LXXIII.	24.	A nearly perfect atlas, the upper part of the left ulna (apparently gnawed by a small carnivore, and probably belonging to the same animal as in No. LXXIV.), the distal extremity of the humerus, of very light colour, distal epiphyses of the left femur, the right lower carnassial tooth of *Hyæna*; a fragment of the right humerus, the right upper canine, a fragment of the shaft of the femur and of a rib, the penultimate right upper molar, a fragment of the palate and part of the alveolus, the right cuneiform, a fragment of the cranium?, a very much-worn right lower last molar of *Ursus*; a fragment of the right calcaneum, an entire right metacarpal, 8″·5 long, of a whitish colour, dry, fragile, weathered or sun- and air-cracked, especially at the distal end, of *Equus*; the right astragalus and the distal end, apparently gnawed, of the tibia, and fitting the astragalus, and a much-gnawed fragment of posterior border of scapula of *Rhinoceros*; a portion of the second rib, the left outer second phalanx, and the right scapho-cuboid of *C. tarandus*. N.B. Though agreeing in size, the portion of tibia and the astragalus of the *Rhino-*

		ceros would seem to differ too much in colour and condition to allow of the supposition that they belonged to the same individual, or at any rate to have been buried under the same circumstances. The astragalus is nearly black and very heavy; whilst the portion of tibia is light-coloured, and though dendritic, still comparatively very little infiltrated with mineral matter. Only 23 specimens are mentioned in the "Register."
LXXIV.	5.	A perfect right radius, part of the ischium, including the right acetabulum, fragment of a rib, and the third cervical vertebra of *Hyæna*; a last upper molar of *Rhinoceros tichorhinus* in germ.
LXXV.	13.	Portion of pelvis (young), the right patella, fragment of a rib, a metacarpal bone, of *Ursus*; canine of *Felis spelæa*; two ribs (fragments), portion of a metatarsal or metacarpal, and an entire left tibia, 7″·45 long, of *Hyæna*; left upper second premolar, very much worn, of *Rhinoceros*; astragalus of *C. tarandus*; fragment of a Bird's bone (H. F.).
LXXVI.	2.	Left radius, quite perfect, and appearing to pair with that in No. LXXIV., and the anterior portion of left mandible, including the canine and first premolar teeth, of *Hyæna*.
LXXVII.	2.	Detached proximal epiphysis of left humerus of *Ursus*; gnawed fragment of distal end of left metacarpal of *Bos*.
LXXVIII.	1.	Beautiful specimen, imbedded in indurated red clay, of the left mandible of *Canis vulpes*. The bone of the jaw, where visible, and the teeth are very dark-coloured from dendritic infiltration.
LXXIX.	8.	Right second metacarpal of *Equus*, pairing with one in No. XLVIII. Portion of scapula, with glenoid fossa and neck, of *C. tarandus*; neural spine of dorsal vertebra, proximal phalanx, gnawed fragments of metacarpal of various bones (young) of *Ursus*; a nodule of ironstone.
LXXX.	7.	Large part of right tibia, including the entire distal articulation, apparently gnawed by a large carnivore (though probably not *Hyæna*) at either end, of *Equus*; the right condyle of the mandible of *Elephas*; large fragment of right ulna, a fragment of the olecranon, and the upper part of the left ulna of *Rhinoceros*; large portion of the left ulna, of small size, of *Ursus* (*Hyæna*, H. F.); odontoid process of axis of *C. tarandus*.
LXXXI.	8.	Much-worn lower molar of *Rhinoceros*; left second premolar and much-worn canine of *Hyæna*; fragments of ribs and long bones of *Ursus*?, femur? of *Hyæna*, and fragments of a large long bone, *Bos*; fragments of ribs of *Ursus*? and *Bos*?, or *Cervus*.
LXXXII.	2.	Right upper canine of *Hyæna*; same tooth of *Ursus*.
LXXXIII.	3.	Right penultimate upper molar, and large lower molar of probably the same individual, of *Rhinoceros*; right upper molar of *Equus*.
LXXXIV.	5.	Detached distal epiphysis of left tibia of *Equus*; gnawed metatarsal or metacarpal of *Hyæna*; right os magnum (pisiforme, H. F.) of *Rhinoceros*; a fragment of rib of small *C. tarandus*, and a rolled splinter of a small long bone.
LXXXV.	1.	Small antepenultimate molar of *Ursus*, exactly corresponding with the same tooth in *U. arctos*.
LXXXVI.	3.	Left upper molar of small *Equus*; fragments of metacarpals or metatarsals, probably of *Ursus*; fragment of a very young bone, *Ursus*?
LXXXVII.	2.	Fragment of fourth cervical vertebra of young *C. tarandus*?, bone straw-coloured, very light and fragile; fragment of tibia of young Hare, both in similar condition to those in No. CIV.
LXXXVIII.	1.	Portion of right maxilla, with four teeth *in situ*, of *Bos*.
LXXXIX.	4.	Right astragalus, gnawed fragment of middle of shaft of right humerus of *Rhinoceros*; proximal end of ulna of *Hyæna*; right upper canine and fragment of shaft of left tibia of *Ursus*.
XC.	11.	Portions of two cervical vertebræ, a gnawed metacarpal, all light-coloured and porous, three molars, dark-coloured and heavy, of *Ursus*; a canine, much-worn premolar, both heavy and dark-coloured, of *Hyæna*; left outer incisor of *Felis spelæa*, very much worn, and in size &c. exactly corresponding with the same tooth *in situ* noted in No. LXI.; gnawed fragment of distal end of right humerus of *C. tarandus*; an amorphous fragment, dark-coloured and heavy (fragment of mandible of *Hyæna*?).
XCI.	12.	Fourth cervical vertebra, gnawed splinter of femur of *Bos* (*B. taurus*?)—the cervical vertebra corresponds with that in No. XCII.; portion of shaft of right humerus of *C. tarandus*?; a premolar tooth of *Cervus elaphus*?; three phalanges of light yellow colour, the right upper canine (slender form), and two fragments of rib of

		Ursus; a metatarsal or metacarpal of *Hyæna*; an upper molar of *Rhinoceros* (testo H. F., and said by him to be something like *R. hemitœchus*); the splinter of a long bone? not determinable, of remarkably close texture and great thickness.
XCII.	25.	Large portion of right tibia, including the lower articular surface, and two other fragments apparently of bones of *Rhinoceros*, all greyish-coloured and dendritic, but not heavy; portion of the left mandible with the three hinder molars, the three separate molars of the same side, the left astragalus of *Equus*; the left calcaneum pairing with No. XXXV., the seventh cervical vertebra, seven or eight portions of ribs, two large metacarpals or metatarsals, distal end of the radius (young), the left lower canine, dark-coloured and dendritic, of *Ursus*; a smaller metacarpal, probably of *Hyæna*; the tibia of a young Hare; portion of a tibia of large *Bos*?; the right os magnum of *C. elaphus*, 1″·6 × 1″·6; the third cervical vertebra of smaller *Bos* (*vide sup.* No. XCI.); gnawed fragment of long bone, *Bos*?
XCIII.	1.	Portion, about 6 inches long, of the shaft of femur of *Elephas* (crushed and quite hollow, filled up with red clayey earth; the shell of bone dark-coloured, dense and polished, and altogether in a different condition from those included under No. LXXII.).
XCIV.	1.	Left metacarpal of *Bos*, probably young, as the distal epiphysis, together, however, with the epiphysial surface, is absent; the bone is sun-cracked and slight: a small species, the upper end measuring only 1″·75 × 3″·1.
XCV.	8.	Lower half, much broken and gnawed, of the right humerus of *Rhinoceros* (*tichorhinus*, H. F.), fragment of arch of dorsal vertebra of *Elephas*, and gnawed fragment of bone of same; fragment of humerus of *Bos* of large size; anterior portion of atlas of *C. tarandus*, very dark peat-colour; base of shed horn of *Cervus elaphus* with large unworn burr, very well developed—the brow-antler is given off immediately above the base, the circumference of which above the burr is 7″ (*Strongylocerine*, H. F.); second right metacarpal of a fragment of right humerus of *Ursus*, nearly perfect and of grey colour; a fragment apparently of a palmate horn, having a deepish notch on one side, much resembling one made by a blunt or stone implement (H. F.), or it may be by the canine of a *Hyæna*.
XCVI.	2.	Seventh cervical vertebra agreeing exactly with that noticed under No. LXXIV., and doubtless belonging to the same animal, and a small fragment of a rib of *Hyæna*?
XCVII.	425.	A boxful of bones of several species of *Arvicola*, *Sorex*, *Weasel*, *Birds*, &c., found lying on the surface of the third bed.
XCVIII.	68.	A similar collection of bones of small animals.
XCIX.	26.	Seventeen bones of Birds, some like those of a Duck or Merganser, others smaller; the skull of *Fœtorius putorius*, and the mandible of another of rather larger size; the tibia of a young Hare; the right os innominatum of *Canis vulpes*; two mandibles of *Arvicola amphibius*; the fore part of the cranium and maxilla of *Lagomys spelæa* (H. F.); a small vertebra.
C.	2.	Left maxilla and mandible of *Canis vulpes*; dentition entire and in beautiful condition. The bone is white, dry, and adherent, incrusted with a very thin layer of hard red crystalline stalagmite. Exactly in the same condition as many of the Gibraltar bones.
CI.		Only earth and stones.
CII.	1.	Fourth rib of *Ursus*.
CIII.	29.	Twenty-five portions of the skeleton of a young Bear, and apparently all belonging to the same individual: the collection includes the proximal ends of both femora (head 1″·65 in diam.); the greater part of the right mandible, containing the canine, third premolar, sockets of two small premolars, one close to the canine and the other to the $\overline{3\ \mathrm{pm}}$; the diameter of the canine on the base of the enamel is 0″·7 × 0″·5. Fragments of the cranium and right and left third premolars of *Ursus*.
CIV.	7.	Upper part of cranium with the bosses for the horns and a considerable part of the occipital, the distal end of the right femur with small part remaining of the outer condyle, the remainder having apparently been gnawed off, and four or five teeth of young *C. tarandus*?
CV.	3.	Large part of tibia, much gnawed and weathered, of *Hyæna*?, rather larger and thicker than the one included in No. LXXV.; gnawed fragment of horn of *C. tarandus*; small gnawed fragment of cannonbone of *Capreolus* (cf. Nos. LXXX. & LXXXVI.).
CVI.	14.	Broken bones of Hares. Rabbits, Birds, &c.; fragment of rib of *Ursus*, light colour, and portion of a dorsal spine.
CVII.	11.	Several bones of a very young Bear. A tibia belonging to this collection is drilled through the middle with a perfectly circular hole about $\frac{1}{8}$ inch in diameter, and exactly of the same size and in the same situation as in the opposite tibia, clearly belonging to the same animal contained in the find No. CVIII. The edges of the

		holes on both sides are slightly chipped, but the sides within are even and smooth. All the bones are light-coloured, slightly dendritic, porous, and fragile. A small fragment of the pelvis of a very young and small ruminant (Sheep or Goat); the scapho-cuboid of the same animal, a slightly gnawed and abraded astragalus of small *Bos*?, and a fragment of a tibia of a small *Bos*?; a fragment of the os innominatum of a young Hare? and Fox.
CVIII.	7.	The shaft of a tibia of a very young *Ursus*, with a circular hole drilled through the middle (*vid. sup.*); the upper bone of the sternum of the same; three teeth (molar, canine, and incisor) of *Ursus*, all partly in germ and probably belonging to the same animal as the bones above noticed; portion of 1st rib, left side, portion of the shaft of a long bone, same size as one in No. XIII., and probably of *C. tarandus*?, dark-coloured and dense; rest light, porous.
CIX.	7.	Left mandible of young Bear with milk-dentition (H. F.); a worn old incisor with the fang, *Ursus*; five fragments of the cranium of *Ursus*.
CX.	1.	Upper half of tibia of *C. tarandus*; the bone is of a light cream-colour, incrusted in parts with hard red crystalline stalagmite, and evidently corresponding to the femur noticed under No. CIV.
CXI.	3.	Butt-end of shed horn, of large size, of *Cervus elaphus*, circumference immediately above the burr 9″·15; a metacarpal or metatarsal of *Hyæna*; splinter of humerus of *Cervus*?
CXII.	3.	Gnawed splinters of long bones, two probably bovine, one of *Ursus*?
CXIII.	4.	Proximal end of right radius of *C. tarandus*; right astragalus pairing? with one noticed under No. LXII., and right upper molar, scarcely worn, of *Rhinoceros*; portion of calcaneum, the apophysis broken off, of *Ursus*.
CXIV.	4.	Gnawed and broken fragment of left astragalus of *Rhinoceros*; proximal phalanx of *C. tarandus*; splinter of tibia of *Bos*; metacarpal, split down the middle and gnawed at one end, of *Bos*, said to have been found associated with two flint fragments 4 feet deep in the third bed, highly dendritic.
CXV.	3.	Second phalanx of *Cervus*; a detached incisor of *Hyæna* (H. F.); a splintered fragment. N.B. I have been unable to find the incisor tooth mentioned here, but which is noticed in Dr. Falconer's notes.
CXVI.	2.	Fragment of a flat bone —— ? (H. F.); "a fine small tibia of —— ? (H. F.); a flint fragment.
CXVII.	1.	Upper part of left radius of small *Ursus*.
CXXII.	4.	Four molars of *Equus*, fresh-looking.
CXXIV.	1.	Fragment of long bone of *Elephas*?
CXXV.	2.	Fragment of right scapula of *Elephas*?; another fragment.
CXXX.	1.	Tooth, premolar of *Hyæna* (H. F.).
CXXXI.	2.	An amorphous fragment (gnawed).
CXXXV.	3.	Two fragments of long bone of *Rhinoceros* or *Elephas*?; gnawed splinter of tibia of *Bos*.
CXLI.	2.	Gnawed fragment of scapula of *Ursus*, of large size.
CXLIII.	1.	A great antler of *Cervus tarandus*.

Appendix.—Concerning specimens either not in the "Register" or doubtful.

1. In Dr. Falconer's Notes a description is given under "No. XCII." of a magnificent specimen, consisting of the femur, tibia, and astragalus *in situ*, together with the radius and a large rib of a Great Bear, termed by him *U. spelæus*. These bones all lie very close together, and must have been originally deposited whilst connected by the soft parts. They are light and fragile and remarkably perfect, imbedded in an indurated red clay. I am unable to perceive any difference between the bones in question and those of *U. arctos*. The entire mass was contained in a separate box. It is alluded to in Dr. Falconer's (p. 478) and in Mr. Pengelly's Report, and seems to have been found over the specimens described under No. XCII.

2. *The contents of a Box marked* B.—The specimens contained in this box are said to have been found in some or other of the Devonshire caves, and were placed in Mr. Philp's glass cases by Mr. Bartlett. The specimens in the box include teeth of Horse (recent) and of the domestic Ox, together with a fragment of horn of Red Deer and bones apparently of Roebuck. The contents appear therefore to be all of domesticated animals; if found in caves, they must have been quite superficial.

3. The specimens numbered CII. to CX., inclusive, were found by Mr. Philp before he leased the cave to the Committee, and were placed by him in a glass case for exhibition.

4. The missing numbers in the above refer to the "finds" of flints described elsewhere.

PART II.—Lists of the Sites in which the remains of each species of Animal were found.

N.B. In the following lists the numbers in the first column (I.) are those of Mr. PENGELLY'S "Register," and they correspond with the numbers in the preceding part of this Report, under which will be found the other specimens with which those noted in these lists were associated. In column II. the distance in feet from the entrance of the Gallery is given as stated in the "Register." Column III. gives the depth in inches at which each "find" occurred, whilst the bed in which it lay is stated in column IV. (in which column a cipher signifies the stalagmite), and the number of specimens belonging to each animal in column V. (See also Tables I. and III. pp. 489 & 492.)

1. ELEPHAS.

a. *Reindeer Gallery.*

I.	II.	III.	IV.	V.	
LXXX.	34	58	3	1	Condyle of lower jaw; on surface of fourth bed, but the ground had been disturbed.
XCV.	81	8	,,	1	Portion of arch of a dorsal vertebra.
Mean....	57	33	..	2	

b. *Flint-knife Gallery.*

XCIII.	49	6	4	1	A portion of shaft of femur, 6″ long.

c. *West Chamber.*

LXXII.	5	156	3	4	An astragalus, three fragments of a tibia.

d. *South Chamber.*

LXIX.	..	..	0	..	Two fragments of bone; on the stalagmite floor.
CXXIV.	14	24	3	1	Portion of tibia.
CXXV.	14	30	,,	2	Fragment of scapula? and of another bone.
Mean....	14	27	..	3	

e. *Steep Slide Hole.*

CXXXV.	28	12	3	1	Fragment of long bone.

2. RHINOCEROS.

a. *Reindeer Gallery.*

III.	19	24	3	1	Gnawed fragment of tibia?
IV.	20	24	,,	1	Gnawed fragment of tibia?
VI.	24	18	,,	1	Lower molar tooth, fragment of.
VII.	29	12	,,	2	Gnawed splinter of left scapula (*vide* No. LXXIII.); part of nasal bone?
XII.	47	10	,,	1	Gnawed fragment of femur.
XIII.	76	6	,,	1	Gnawed fragment of scapula?
XIX.	71	30	,,	1	A gnawed fragment of left ulna.
LXXX.	34	58	,,	3	Portion of ulna; right olecranon; upper part of left ulna.
LXXXI.	24	42	,,	1	A lower molar, much worn.
LXXXIII.	16	42	,,	2	Two teeth, upper and lower molars.
LXXXIV.	26	42	,,	1	The right os magnum, quite perfect.
LXXXIX.	82	58	,,	2	Middle portion of shaft of right humerus, gnawed at each end.
XCI.	85	36	,,	1	An upper milk-premolar tooth.
XCII.	86	36	,,	3	A large portion of right tibia; two gnawed fragments.
XCV.	81	8	,,	3	Lower half, broken and gnawed, of right humerus; fragments of vertebra &c.
CXIII.	20	54	,,	2	An upper molar tooth; left astragalus, slightly gnawed (*vide* No. LXII.).
CXIV.	18	48	,,	1	Gnawed fragment of right astragalus.
Mean....	45	32	..	27	

2. Rhinoceros (continued).

b. *Flint-knife Gallery.*

I.	II.	III.	IV.	V.	
XXII.	1	9	3	1	Much-gnawed fragment of lower end of tibia.
XXIX.	10	2	0	1	Lower two thirds of the right femur.
XXXVI.	17	13	3	1	Gnawed and weathered ? fragment of humerus ?
XXXIX.	20	24	,,	1	An amorphous fragment.
XLIV.	34	58	,,	1	A fragment, gnawed.
XLVIII.	42	42	,,	1	Much-gnawed fragment of upper part of tibia.
LI.	40	60	,,	1	Gnawed fragment of left femur.
LII.	46	60	,,	5	Two teeth; three fragments of the seventh cervical vertebra.
LVI.	4	63	,,	1	An upper molar, in germ.
LXI.	4	60	,,	2	Two lower molars, one in germ.
LXII.	3	57	,,	7	Six molar teeth; the right astragalus, entire.
Mean....	20	40	..	22	

c. *West Chamber.*

LXIII.	8	84	3	3	Three lower molars, of large size.
LXIV.	6	108	,,	3	Two upper molars, one probably a milk-tooth; an amorphous fragment?
LXXII.	5	156	,,	2	An upper milk-molar and a lower molar.
LXXIII.	5	156	,,	3	Gnawed lower end of tibia; right astragalus; portion of scapula (*vide* No. VII.).
LXXIV.	5	156	,,	1	A lower molar, in germ.
LXXV.	5	156	,,	1	An upper molar tooth.
Mean....	6	136	..	13	

d. *South Chamber.*

LXIX.	?	?	0	1	A gnawed fragment; on stalagmite floor, 16 inches from roof.
LXXI.	?	?	0	1	Two fragments of pelvis, with the acetabulum entire (immediately beneath stalagmite).
CXXIV.	10	24	3	1	Fragment of femur?
				3	

e. *Steep Slide Hole.*

CXXXV.	28	12	3	2	Fragments of long bone (*Elephas* ?).

3. Equus.

a. *Reindeer Gallery.*

IV.	20	24	3	2	Two gnawed fragments of the same tibia.
VII.	29	12	,,	1	Much-gnawed fragment of radius (young).
LXXX.	34	58	,,	2	Great part of tibia; articular end of humerus, gnawed.
LXXXIII.	16	42	,,	1	An upper left molar.
LXXXIV.	26	42	,,	1	Detached epiphysis of tibia (attached to underside of stalagmite).
LXXXVI.	34	24	4	1	Upper molar (small).
XCII.	86	36	3	5	Part of mandible with three molars; an astragalus; three detached molars belonging to the same jaw.
Mean....	35	34	..	13	

3. Equus (continued).

b. *Flint-knife Gallery.*

I.	II.	III.	IV.	V.	
XXII.	1	9	3	1	Lower two thirds of humerus.
XXXV.	10	36	,,	1	A proximal phalanx.
XL.	24	34	,,	2	Two fragments of ischium and pubis.
XLII.	26	33	,,	1	An outer metacarpal (pairs with No. LXXIX.).
XLIV.	34	58	,,	1	The glenoid fossa and neck of scapula.
XLVI.	49	30	,,	1	A metacarpal, gnawed.
XLVIII.	42	42	,,	1	The fourth metatarsal.
LII.	46	60	,,	1	A second phalanx, fitting into No. XXXV. (colour different).
LXII.	3	57	,,	1	An entire radius.
LXXIX.	3	42	,,	1	An outer metacarpal (pairs with No. XLII.).
Mean....	24	40	..	11	

c. *West Chamber.*

LXXIII.	5	156	3	2	Part of calcaneum; an entire right metacarpal.

d. *South Chamber.*

CXXII.	14	3	3	4	Four teeth, of small size.

4. Bos.

a. *Reindeer Gallery.*

XII.	47	10	3	1	Fragment of cannonbone.
LXXXVIII.	82	0	,,	1	Portion of maxilla with four teeth (*Bos primigenius*); under the floor (Plate XLVI. fig. 11).
XCI.	85	36	,,	1	Fourth cervical vertebra (*Bos* —— ?).
XCII.	86	36	,,	1	Third cervical vertebra of same animal.
XCIV.	24	6	4	1	Left metacarpal, wanting the lower end (small size).
XCV.	81	8	3	1	Fragment of humerus?
CXIV.	18	48	,,	1	A metacarpal, split and gnawed at one end.
Mean....	60	21	..	7	

b. *Flint-knife Gallery.*

XXII.	1	9	3	1	Lower end of right radius.
XXXII.	9	33	,,	1	Fragment of cannonbone, gnawed.
XXXVII.	19	28	,,	4	m 2 of *B. primigenius*?; three fragments of sixth cervical vertebra, corresponding with Nos. XCI. & XCII.
XL.	24	34	,,	1	m 3 of *B. primigenius*? much worn.
XLV.	36	60	,,	1	Fragment of tibia.
XLVIII.	42	42	,,	1	Fragment of tibia.
LI.	40	60	,,	2	m 3; gnawed fragment of tibia.
LII.	46	60	,,	2	mm 2, much worn; a pm very little worn, of large size.
LVI.	4	63	,,	1	Gnawed fragment of left tibia (*B. primigenius*?).
LXII.	3	57	,,	1	Neck of scapula.
LXXVII.	40	96	,,	1	Gnawed fragment of left metacarpal.
CVII.	10	0	,,	1	An astragalus, small size (with recent look).
Mean....	24	46	..	17	

4. Bos (continued).

c. *West Chamber.*

I.	II.	III.	IV.	V.	
LXIII.	8	84	3	2	pm 3; fragment of humerus.
LXIV.	6	108	,,	1	Portion of olecranon.
LXXII.	5	156	,,	1	Neck of right scapula.
Mean....	7	116	..	4	

5. Cervus elaphus.

a. *Reindeer Gallery.*

XI.	47	9	3	2	Gnawed and weathered fragments of base of horn.
XCII.	86	36	,,	1	The right os magnum (1·6 × 1·6).
XCV.	81	96	,,	1	Base of shed horn, with rose entire and origin of brow-antler (nearly black).
CXI.	28	42	,,	1	Base of large horn (*Strongylocerine*, H. F.).
CXV.	15	108	,,	1	A second phalanx (H. F.) (black colour). See CXV. p. 513.
Mean....	51	46	..	6	

b. *Flint-knife Gallery.*

XLVII.	42	36	3	2	Portions of a small cylindrical antler and of a larger one.
LXII.	3	57	3	1	The water-rolled base of a shed horn.
Mean....	22	46	..	3	

c. *West Chamber.*

LXXII.	5	13	3	1	Gnawed or weathered and rolled fragment of base of horn.

d. *South Chamber.*

LXVIII.	6	0	..	2	Portion of maxilla with two unworn molars, and a much-worn milk-molar, $\overline{2}$ m, large size; found on the stalagmite floor.

6. Cervus tarandus.

a. *Reindeer Gallery.*

IV.	20	24	3	2	Lower end of tibia?; portion of horn.
V.	23	21	,,	1	Fragment of right astragalus.
VI.	24	18	,,	1	Base of sacrum.
VII.	29	12	,,	1	Small snag of horn (H. F.).
X.	32	6	,,	2	Portion of shaft of young femur; much-worn molar.
XIII.	76	6	,,	2	A proximal phalanx; a splinter of long bone?
XV.	67	7	,,	1	A left calcaneum.
XIX.	71	30	,,	1	Gnawed fragment of left radius.
CXLIII.	74	0	,,	1	A great antler, found on stalagmite floor over the Ebur Chasm.
LXXX.	34	58	,,	1	Odontoid process.
LXXXI.	24	42	,,	1	Gnawed splinter of right radius.

6. CERVUS TARANDUS (continued).

a. *Reindeer Gallery* (continued).

I.	II.	III.	IV.	V.	
LXXXIV.	26	42	3	1	Fragment of rib.
LXXXVII.	81	8	0	1	Fragment of cervical vertebra; in stalagmite floor.
XC.	83	48	3	1	Gnawed fragment of lower end of right humerus.
XCI.	85	36	,,	1	Portion of shaft of humerus.
XCII.	86	36	,,	1	The left astragalus.
XCV.	81	8	,,	2	Gnawed fragment of atlas; a fragment of horn?
CIV.	32	0	0	1	Upper part of young cranium; portion of femur gnawed; four teeth.
CV.	34	24	3	2	A fragment of horn (gnawed); splinter of metatarsal.
CXI.	28	42	,,	1	Splinter of humerus?
CXIII.	20	54	,,	1	Upper end of left radius.
CXIV.	18	48	,,	1	Proximal phalanx.
Mean....	48	26	..	26	

b. *Flint-knife Gallery.*

XXII.	1	9	3	1	Outer trochlea of left metacarpal.
XXIX.	10	2	0	1	Greater part of left metatarsal, the lower ends wanting. In the stalagmite.
XXX.	11	3	3	1	Fragment of left calcaneum; same condition as No. X.
XXXII.	9	33	,,	1	Lower half of right humerus.
XXXV.	10	36	,,	1	A proximal phalanx.
XXXVI.	17	13	,,	1	Lower half of humerus; superficially gnawed.
XXXVIII.	23	4	,,	1	Lower end of left metacarpal.
XXXIX.	20	24	,,	3	Lower half of tibia; lower end of tibia; point of antler.
XL.	24	34	,,	1	Gnawed fragment, 6·6 long, of horn, with brow- and second antler.
XLIV.	34	58	,,	4	An entire right radius; fragment of horn; part of atlas and of tibia.
LI.	40	60	,,	5	Calcaneum; proximal phalanx; portion of ilium femur, &c.
LII.	46	60	,,	2	Atlas; second lumbar vertebra.
LIII.	49	36	,,	1	Right metatarsal.
LV.	3	48	,,	1	Upper half of left radius (*vide.* CXIII.).
LVI.	4	63	,,	4	Left tibia; scapho-cuboid; astragalus; fragment of cannonbone.
LXI.	4	60	,,	1	Base of sacrum.
LXII.	3	57	,,	1	Extremity (gnawed) of metatarsal.
LXXIX.	3	42	,,	1	Portion of left scapula.
CVII.	10	0	,,	2	Left scapho-cuboid (small); lower half of left tibia with epiphysis detached.
CVIII.	14	0	,,	1	Fragment of shaft of femur?; portion of a rib, left side.
CX.	22	0	,,	1	Upper end of left tibia (*vide* CIX.).
Mean....	17	30	..	35	

c. *West Chamber.*

LXIII.	8	84	3	1	An entire left calcaneum.
LXIV.	6	108	,,	3	Shaft of right humerus; much-gnawed lower end of tibia; portion of acetabulum.
LXX.	7	48	,,	1	Lower end of right metacarpal.
LXXII.	5	156	,,	1	Detached epiphysis of right tibia.
LXXIII.	5	156	,,	3	Head and neck of second left rib; a proximal phalanx; scapho-cuboid.
LXXIV.	5	156	,,	1	An old, much-worn upper molar.
LXXV.	5	156	,,	1	Left astragalus.
Mean....	6	118	..	11	

7. CAPREOLUS.

a. *Reindeer Gallery.*

I.	II.	III.	IV.	V.	
VII.	29	12	3	1	Base of horn (?).
XIII.	76	6	,,	2	Right metatarsal, portion of pelvis; light-coloured, porous.
XIV.	70	2	,,	2	Proximal phalanx; portion of calcaneum; light-coloured, porous.
CV.	34	24	,,	1	Small gnawed fragment of cannonbone (ground disturbed).
Mean....	52	11	..	6	

b. *Flint-knife Gallery.*

XXII.	1	9	3	1	Left hind proximal phalanx.
XXVIII.	7	0	,,	1	Entire left metacarpal (immediately beneath stalagmite).
XXXVIII.	23	4	,,	2	Right metatarsal; portion of shaft of femur.
XLVIII.	42	42	,,	1	Lower extremity of right tibia.
LI.	40	60	,,	2	Fragments of long bones (?).
Mean....	28	29	..	7	

8. FELIS SPELÆA.

a. *Reindeer Gallery.*

XC.	83	48	3	1	Left outer incisor (0·50 × 0·45).

b. *Flint-knife Gallery.*

XXXI.	7	16	3	1	A fifth proximal phalanx (Plate XLV. fig. 7).
XXXIX.	20	24	,,	1	A ? ,, ,, (Plate XLV. fig. 8).
LII.	46	60	,,	1	A much-worn canine (*vide* Rel. Diluv.).
LVI.	54	63	,,	1	Fragment of right maxilla, with pm 1 and pm 2.
LXI.	54	60	,,	2	Fragment of left maxilla, with pm; a second portion of same jaw with outer incisor *in situ*.
Mean....	36	45	..	6	

c. *West Chamber.*

LXXV.	..	156	3	1	A canine tooth (Plate XLV. fig. 5).

d. *South Chamber.*

LXVI.	6	?	?	1	A right upper carnassial tooth (1·5 × 0·75), Plate XLV. fig. 6.

9. Hyæna.

a. *Reindeer Gallery.*

I.	II.	III.	IV.	V.	
VII.	29	12	3	1	Lower canine (0·62 × 0·54).
VIII.	39	9	,,	1	Metatarsal or metacarpal (?).
XIX.	71	30	,,	2	Calcaneum; upper canine (0·69 × 0·52).
LXXXI.	24	42	,,	3	Second premolar, upper canine, much worn; fragment of femur, gnawed (?).
LXXXII.	10	42	,,	1	Upper canine.
LXXXIV.	26	42	,,	1	Gnawed metacarpal or metatarsal.
LXXXIX.	82	58	,,	1	Proximal end of ulna.
XC.	83	48	,,	2	Lower canine (0·65 × 0·50); third lower premolar (0·91 × 0·55).
XCI.	85	36	,,	1	A metacarpal or metatarsal.
XCII.	86	36	,,	1	A metacarpal or metatarsal.
CV.	34	24	,,	1	Shaft of right tibia, gnawed (? small *Ursus*).
CXI.	28	42	,,	1	A metacarpal or metatarsal.
CXV.	15	108	,,	1	Incisor tooth (H. F.). (In a pipe of cave-earth penetrating 5 feet deep in the gravel bed No. 4.)
CXXX.	50	9	,,	1	A premolar (H. F.).
Mean....	47	37	..	18	

b. *Flint-knife Gallery.*

XXVIII.	7	0	3	1	Canine tooth, dark-coloured (immediately beneath stalagmite).
XXXI.	7	16	,,	2	Upper canine; a metatarsal or metacarpal.
XLVIII.	42	42	,,	1	A proximal phalanx.
L.	36	54	,,	1	Lower canine, much worn, and corresponding with No. XXXI.
LII.	46	60	,,	1	Lower canine.
LVI.	4	63	,,	8	Portion of left mandible, with second and third premolars, and six separate teeth.
LXI.	4	60	,,	1	Shaft of left femur.
LXII.	3	57	,,	2	First upper molar; detached capital epiphysis of femur.
LXV.	50	66	,,	1	Portion of rib (?), &c.
Mean....	22	48	..	18	

c. *West Chamber.*

LXIII.	8	84	3	2	Two upper canines (0·6 × 0·5 and 0·65 × 0·5).
LXIV.	6	108	,,	3	Lower end of left tibia; right mandible with three teeth; a canine tooth (0·65 × 0·48).
LXXIII.	5	156	,,	5	An entire atlas; portions of ulna, humerus, femur, &c.; a lower carnassial tooth (1·32 × 0·55).
LXXIV.	5	156	,,	4	A perfect right radius; portion of pelvis; ribs; third cervical vertebra.
LXXV.	5	156	,,	4	A perfect tibia; three fragments of ribs; a metatarsal or metacarpal?
LXXVI.	6	122	,,	2	A perfect left radius; portion of left mandible, with four teeth *in situ*.
XCVI.	6	122	,,	1	A seventh cervical vertebra, corresponding with No. LXXIV.
Mean....	6	129	..	21	

10. URSUS.

a. *Reindeer Gallery.*

I.	II.	III.	IV.	V.	
IV.	20	24	3	2	Canine tooth; lumbar vertebra, much gnawed.
VII.	29	12	,,	1	Gnawed fragment of left radius.
VIII.	39	9	,,	2	Fragments of radius and of a rib.
IX.	37	6	,,	1	Fragment of rib.
XIII.	76	6	,,	1	Small proximal phalanx.
XIV.	70	2	,,	1	Lower canine tooth (enamel cap).
XVI.	71	30	,,	1	A lower canine tooth.
XVII.	67	0	..	1	A perfect right humerus of small size, in chalky matrix, *U. arctos.*
XVIII.	36	36	3	1	A large much-worn upper canine (1·5 × —).
XIX.	71	30	,,	7	Right unciform (large size); fourth metatarsal; a proximal phalanx; lower canine; an upper molar; fragment of cranium.
XXI.	70	14	,,	3	Lower canine; two phalanges.
XXIII.	69	28	,,	3	Three fragments of metacarpals and metatarsals.
XXIV.	68	33	,,	30	Scapho-lunar bone (Plate XLVI. fig. 10); twenty-nine other bones of very large size.
LXXX.	34	58	,,	1	Large part of left ulna, gnawed at each end, light-coloured, porous.
LXXXI.	24	42	,,	1	Gnawed fragment of shaft of femur, of large size, nearly black.
LXXXII.	10	42	,,	1	Upper canine tooth.
LXXXVI.	34	24	4	2	A gnawed metacarpal; fragment of metatarsal or metacarpal.
LXXXIX.	82	58	3	2	Upper canine; fragment of left tibia.
XC.	83	48	,,	6	Three molar teeth; portions of two cervical vertebræ; a much-gnawed metacarpal.
XCI.	85	36	,,	5	Canine; three phalanges; fragment of rib.
*XCII.	86	36	,,	13	Entire left calcaneum, pairing with No. XXXV.; seventh cervical vertebra; two metatarsals; a canine tooth in germ, of large size, &c.
XCV.	81	8	,,	2	A metacarpal; portion of right humerus.
CII.	3	36	1	1	Portion of rib.
CIII.	10	30	1	27	Twenty-five portions of young skeleton; two adult teeth.
CXIII.	20	54	3	1	Portion of calcaneum, much gnawed.
Mean....	53	28	..	116	

b. *Flint-knife Gallery.*

XXII.	1	9	3	3	A canine tooth; shaft of humerus; young tibia.
XXV.	4	0	,,	1	pm 2, imbedded in angular breccia.
XXVI.	3	6	,,	10	Nine teeth; $\overline{\text{pm 4}}$, *in situ*, of young animal; an ungual phalanx.
XXVII.	3	9	,,	1	An enamel cap of canine.
XXIX.	10	0	..	2	Left mandible of young animal, pairing with No. XXVI.; shaft of young femur.
XXX.	11	3	3	7	Three enamel caps of canines; a small incisor; a perfect metacarpal; a mature calcaneum.
XXXI.	7	16	,,	3	Two fragments of metatarsals or metacarpals (? *Felis*); portion of rib.
XXXIV.	12	9	,,	3	Second incisor; canine of the slender form.
XXXV.	10	36	,,	3	Shaft of left femur of young animal; right calcaneum, pairing with No. XCII.; portion of metatarsal.
XXXVI.	17	13	,,	2	Canine (slender); $\overline{\text{pm 4}}$.
XXXVII.	19	28	,,	1	A metatarsal.
XXXIX.	20	24	,,	1	A metatarsal bone (? *Felis*); fragment of ischium, very dark colour.
XL.	24	34	,,	3	Much-gnawed fragments of ilium and scapula; gnawed fragment of inner condyle of humerus.
XLI.	29	14	,,	1	Large unworn canine.
XLII.	26	33	,,	4	A metacarpal; metatarsal; fragments of radius and ulna, large size.

---

* *Vide* Appendix, p. 506.

10. Ursus (continued).

b. *Flint-knife Gallery* (continued).

I.	II.	III.	IV.	V.	
XLIII.	40	0	3	1	An upper canine, of small size, much cracked and weathered (*U. arctos*).
XLIV.	34	58	,,	6	Left mandible of mature animal; a metatarsal; a molar tooth; olecranon, and fragment of shaft of ulna.
XLV.	36	60	,,	1	A metatarsal bone.
XLVI.	49	30	,,	1	Fragment of humerus.
XLVII.	42	36	,,	4	Extremity of left mandible, with canine *in situ*; fragment of pelvis and the left parietal bone; fragment of ulna.
XLVIII.	42	42	,,	4	Three teeth; fragments of radius and tibia, both young.
XLIX.	26	42	,,	1	Part of right mandible, with canine and penultimate molar *in situ* (pairs with No. XLIV.).
LI.	40	60	,,	9	Fragments of various bones, young and old.
LII.	46	60	,,	50 or 60	Thirty or forty bones and teeth of a very young animal; gnawed fragments of scapula, ribs, &c.; broken astragalus of mature age, black (Plate XLVI. fig. 8).
LIII.	49	36	,,	1	Gnawed fragment of rib.
LVI.	54	63	,,	1	Portion of shaft of left tibia of large size.
LVII.	54	60	,,	39	Bones of the skeleton of a young animal.
LVIII.	54	96	,,	5	Teeth of various ages (*U. priscus*?).
LX.	52	54	,,	2	An outer incisor, dark-coloured; fragment of palate.
LXI.	54	60	,,	5	A metatarsal and fragments of other bones.
LXII.	53	57	,,	5	A broken canine; gnawed fragments of various long bones.
LXV.	50	66	,,	1	Gnawed fragment of left humerus.
LXXVII.	40	96	,,	1	Detached proximal epiphysis of humerus.
LXXIX.	3	42	,,	5	Spinous process of dorsal vertebra of large size, a phalanx, and gnawed fragments of other bones.
CVI.	5	0	,,	1	Fragment of rib; broken spinous process (white colour).
CVII.	10	0	,,	7	Various bones of one or more young animals (white colour); the tibia has a hole recently drilled through it.
CVIII.	14	0	,,	6	Other bones and teeth of apparently the same animal; the tibia has also a hole drilled through it (*U. arctos*).
CIX.	16	0	,,	7	Portion of lower jaw with milk-teeth (same animal?); a worn old incisor of dark colour; five fragments of other bones.
CXVII.	14	0	,,	1	Fragment of left radius, corresponding with the ulna in No. LXXX.; imbedded in the stalagmite together with a shell of *Helix* ——?
Mean....	28	32	..	209	

c. *West Chamber.*

LXIII.	8	84	3	5	Three teeth; a metacarpal; os unciforme, small and dark-coloured.
LXIV.	6	108	,,	7	Three teeth; fragment of right mandible with old worn stump of $\overline{m\ 1}$; right half of atlas; a sternal bone; portion of ischium.
LXX.	7	48	,,	3	Fragment of ulna, gnawed, of small size; shaft of left tibia, gnawed at each end.
LXXIII.	5	156	,,	7	Gnawed fragment of occipital; left ectocuneiform; several teeth and fragments of humerus, parietal, and other bones.
LXXV.	5	156	,,	4	An entire left patella; portion of ischium (young); fragment of rib; a metacarpal bone.
Mean....	6	110	..	26	

d. *South Chamber.*

LXVII.	..	0	..	3	Great part of shaft of femur of young animal imbedded in white chalky matrix; a radius and ulna, gnawed; found in the stalagmite floor (*U. arctos*). (In the stalagmite.)

11. Canis vulpes.

a. *Reindeer Gallery.*

I.	II.	III.	IV.	V.	
I.	15	18	1	1	Carnassial tooth, apparently modern.
XIV.	70	2	3	1	Canine tooth, apparently modern.
XCIX.	110	0	,,	1	Right os innominatum, modern.
C.	110	6	,,	2	Left upper and lower jaws, with the entire dentition; bones in the same condition as the associated Hares, Rabbits, Birds, &c.
Mean....	76	7	..	5	

b. *Flint-knife Gallery.*

XL.	24	34	3	1	An entire humerus (broken across the middle), nearly black, dense, ancient.
LXV.	50	66	,,	2	Lower ends of tibia and radius in same mineralized condition.
LXXVIII.	36	96	,,	1	The entire left mandible with perfect dentition, imbedded in red clay (same condition).
Mean....	37	65	..	4	

12. Bones of Birds and small Mammals (*Lepus*, *Fœtorius*, *Sorex*, *Arvicola*, *Lagomys*, *&c.*).

a. *Reindeer Gallery.*

II.	19	18	1	?	Numerous bones of small Birds, Hare, Rabbit, &c., modern.
XIV.	70	2	3	?	Numerous bones, chiefly young Hares and Rabbits (a Fox's tooth).
XCII.	86	36	,,	1	The tibia of a young Hare, in same recent condition!
XCVII.	115	0	,,	?	Numerous bones of *Arvicola*, *Sorex*, *Weasel*, &c., Birds.
XCVIII.	114	0	,,	?	A similar collection.
XCIX.	110	0	,,	?	Skull of *Fœtorius putorius*; mandible of a second; tibia of Hare; mandible of *Arvicola*; part of cranium and maxilla of *Lagomys spelæus* (H. F.).
Mean....	86	9			

b. *Flint-knife Gallery.*

XX.	2	0	3	?	Numerous bones of very young Hares, &c.
XXV.	4	0	,,	?	Numerous bones of very young Hares, &c.
XXVI.	3	6	,,	?	Lower canine of *Meles taxus*, dark colour.
XXVIII.	7	0	,,	?	Numerous bones of young Hares, Rabbits, &c.
XXIX.	10	2	..	2	Vertebra of Hare; long bone of Bird?, in hard stalagmite.
XXXIII.	12	0	3	9	Bones of Hares, Rabbits, small Bird, some gnawed by *Arvicola*.
XLI.	29	14	,,	1	Sacrum of a Bird?
LIV.	10	48	,,	44	Bones, chiefly of Hare, amongst loose stones with but little earthy matter, in the third bed.
LIX.	4	0	,,	1	Seventh or eighth rib, right side, of Sheep, sawn and quite recent.
CVI.	5	0	,,	14	Numerous, mostly broken, bones of Rabbits, Birds, &c., in contact with the stalagmite.
Mean....	8	7			

c. *West Chamber.*

LXXV.	5	156	3	1	Fragment of a Bird's bone (H. F.).

Part III.—General Remarks on the Animal Remains.

Bones belonging to 20 or 21 species of mammals and of several species of birds were met with. The mammalian species that have been identified with certainty are:—

1. *Elephas primigenius.*
2. *Rhinoceros tichorhinus.*
3. *Equus caballus.*
4. *Bos primigenius.*
5. —— *longifrons.*
6. *Cervus elaphus.*
7. —— *tarandus.*
8. *Capreolus capreolus.*
9. *Felis spelæa.*
10. *Hyæna spelæa.*
11. *Ursus spelæus.*
12. —— *priscus* (s. *ferox fossilis*).
13. —— *arctos.*
14. *Canis vulpes.*
15. *Meles taxus.*
16. *Lepus timidus.*
17. —— *cuniculus.*
18. *Lagomys spelæus.*
19. *Arvicola amphibius.*
20. —— ——?
21. *Sorex vulgaris.*

I. Proboscidia.

1. *Elephas primigenius.*

The remains of the Mammoth occurred in five situations, viz. the Reindeer Gallery, the Flint-knife Gallery, the West Chamber, the South Chamber, and the Steep Slide Hole. For the most part they appear to have lain at a considerable depth, and, with one or two exceptions, are the only remains met with in the fourth bed. In the Reindeer Gallery a well-marked condyle of the lower jaw was found on the surface of the fourth bed; but as the ground in that situation had been previously disturbed, the exact site is uncertain. In the Flint-knife Gallery a fragment of the femur, 6 inches long, occurred at a depth of 6 inches in the same bed; whilst in the West Chamber an astragalus and great part of the corresponding tibia were found at a depth of 13 feet in the third bed, or nearly at its base. In the South Chamber and in Steep Slide Hole the remains (which, it should be remarked, have not been identified with absolute certainty) were met with more superficially. On the whole, it would appear that the elephantine remains occupied the deepest levels in the cavern.

The parts most worthy of attention are:—the condyle of the lower jaw above referred to, the astragalus and tibia found in the West Chamber, and the portion of the shaft of a femur found in the Flint-knife Gallery.

The condyle, which, though evidently gnawed, is very entire, is about 3·5 inches in its transverse diameter, and in size corresponds with that of an African Elephant of the usual size. The form of the condyle also approaches that of the African rather than of the Asiatic Elephant, the resemblance with the former consisting chiefly in its greater thickness compared with the transverse diameter, and the squareness, as it were, of the inner side, where in the Asiatic Elephant the condyle is more rounded and tapering.

The astragalus, which is also nearly entire, is much gnawed, especially on the inner, anterior, and hinder aspects; and the lower end of the tibia found in association with it, and manifestly belonging to the same individual, is also gnawed on the same three sides. The appearance of the bones, therefore, suggests that they were lying together, connected by the soft parts at the time they were gnawed, and that the carnivore (probably Hyæna) had either been unable or had neglected to turn them over. The astragalus measures 5″·4 in the transverse and 5″ in the antero-posterior direction. The portion of femur is a good deal crushed, and it is quite hollow and filled up with red clayey earth: the bone itself is in a different condition from the tibia and astragalus, being more deeply coloured, heavier and denser, whilst its surface is somewhat polished; and from the roundness of the angles at the broken ends, it would seem to have been rolled.

It is a remarkable circumstance that no fragment of the tusk or teeth of the Mammoth should have occurred in the cavern—a circumstance from which it might be supposed that the remains discovered there were merely the relics of parts brought in by Carnivora for prey.

II. PERISSODACTYLA.

2. *Rhinoceros.*

Between sixty and seventy specimens, certainly referrible to Rhinoceros, were met with, of which forty-nine occurred in the "Reindeer" and "Flint-knife" Galleries. In the former situation the specimens occurred at all distances from the entrance from 16 to 86 feet; and they were all lodged in the third bed, at depths varying from 6 to 58 inches, the majority, however, being found at a depth of between 3 and 4 feet: and with respect to this, it may be remarked that in some measure the depth at which the specimens were met with increased in proportion to the distance from the entrance into the Gallery.

In the "Flint-knife Gallery" the Rhinoceros remains occurred at distances of from 1 to 46 feet from the entrance; and they were all lodged in the third bed at a depth, speaking generally, of about 4 feet, the only exceptions being one specimen which was met with within a foot of the entrance, at a depth of only 9 inches, and two others which were lodged at 13 and 24 inches: but it will be remarked that these more superficial sites were all within 20 feet of the entrance, so that the apparent rule that the depth was in proportion to the distance from the entrance of the gallery, is even more strikingly manifested in this locality than in the Reindeer Gallery.

In the West Chamber the few specimens met with occurred at depths of from 9 to 13 feet, also in the third bed, or at a much greater depth than in either of the two preceding localities.

In the South Chamber, however, the case is widely different. In this department of the cavern, the remains of Rhinoceros seem to have been laid quite superficially. One specimen, only doubtfully referred to *Rhinoceros*, and which may have been elephantine, is stated to have been found "on the stalagmite floor." Two other specimens, however, with respect to which there can be no doubt, and consisting of large fragments of the pelvis, including an entire acetabulum 4″·6 in diameter, occurred in this part of the cavern "immediately beneath the stalagmite floor;" whilst a fragment of a femur was met with 10 feet from the west entrance, at a depth of only 2 feet in the third bed, above which lay a cake of stalagmite.

The numerous teeth of both jaws and of all ages appear to me to belong, without exception, to *Rhinoceros tichorhinus*; but I should not omit to mention that, with respect to one specimen among them, Dr. FALCONER appears to have hesitated in opinion, as I find a note of his in which he remarks that "it is something like *R. hemitœchus*."

The Rhinoceros bones and teeth are all dark-coloured and highly dendritic or infiltrated with manganesic oxide: most of them are much gnawed; and amongst these I have selected one of several portions of the shaft of the femur to show the manner in which they have been attacked, undoubtedly by the *Hyæna* (Plate XLIV. fig. 1)*. But some among them are remarkably perfect, presenting no marks of gnawing nor any indication of their having been rolled by water: amongst these are two or three astragali and a remarkably perfect os magnum.

3. *Equus*.

The equine remains include about thirty well-marked specimens, and a few others not so strictly determinable. They all appear to have belonged to the same species, the individuals differing only slightly in stature, which seems to have been from 13 to 15 hands high, and are indistinguishable by any character of the teeth or bones from the existing *Equus caballus*. Remains of animals of various ages are met with, though the majority have been mature, and some aged. The bones themselves differ considerably in condition, some exhibiting every indication of great antiquity, whilst others have a more modern aspect, in which respects the equine remains closely resemble those of the Bear.

Bones of the Horse occurred in the following situations:—

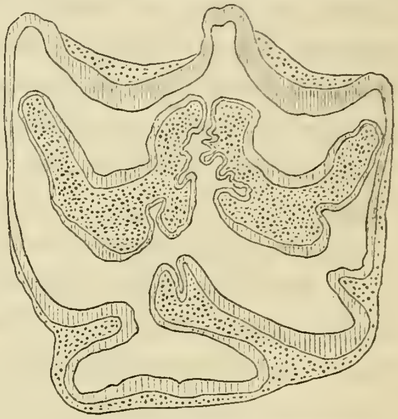
1. Reindeer Gallery, at distances of from 16 to 86 feet from the entrance, and generally at depths in the third bed varying from 12 to 42 inches. The only two exceptions are:—one instance in which it is recorded that the specimen was found on the surface of the fourth bed, but in a spot where it is probable the ground had been previously disturbed; and a second, in which a much-worn tooth was met with at a depth of 24 inches in the fourth bed, associated with bones of the Bear, and in a spot where it is noted that "the ground appeared to be quite undisturbed" (the specimen is that of the first upper molar of the right side, about 1″·6 long and 1″ × 1″ in the crown).

Another tooth, found at no great distance from the above, though at a less depth in the third bed, presents equal signs of great antiquity. It may not improbably have belonged to the same animal, and, like the former, presents all the characters of the corresponding tooth in the existing Horse.

---

* I am informed by Mr. W. BOYD DAWKINS that he has noticed precisely similar gnawed fragments of the femur of *Rhinoceros* in great numbers (I think he said 200) from Wokey Hole. The occurrence, therefore, of such remains may be regarded as diagnostic of the presence of the *Hyæna*, even in the abseuce of its own relics.

Other specimens found in this part of the cavern worthy of note are part of the lower jaw containing the three hinder molars *in situ*, and the three anterior molars belonging to the same jaw and found together with it and an astragalus in association in the same spot with bones of the Rhinoceros, Bear, and Hyæna, as well as with the tibia of a young Hare, the os magnum of *Cervus elaphus*, and the cervical vertebra of a small species of *Bos*. The bone of the jaw in question, which, together with the others above mentioned, was found 86 feet from the entrance of the Gallery at a depth of 3 feet in the third bed, is nearly white, and its surface is partially incrusted, especially on one side, with a thin layer of crystalline stalagmite. It nowhere presents the slightest trace of metallic impregnation. So far as its appearance goes, therefore, it would appear to have belonged to a superficial level, probably in direct contact with, if not above, the stalagmite floor; and this supposition seems to be strengthened by its association with the bones of the Hare, Stag, and small Ox, all of which are in exactly the same condition as similar remains in other parts of the cavern, and found for the most part only in the uppermost or on the surface of the third bed and in immediate contact with the stalagmite. On the other hand, the bones of *Rhinoceros* and *Hyæna* are clearly, from their condition, of vastly greater antiquity, and must have been derived from a much greater depth. It is not easy to account for this mixture of bones in such widely different conditions, except on the supposition that by some accident they had become confounded in the extraction. The jaw and teeth are indistinguishable from those of the existing Horse, as will be seen in the accompanying figure, which shows the enamel flexures in the first upper molar, and in the following dimensions of the individual teeth (the entire series measures 6″·6):—



m 1. ×2 diam.

$\overline{\text{1 pm}}$	1·2 × ·75
$\overline{\text{2 pm}}$	1·1 × ·75
$\overline{\text{3 pm}}$	1·05 × ·75
$\overline{\text{1 m}}$	1·0 × ·75
$\overline{\text{2 m}}$	1·0 × ·63
$\overline{\text{3 m}}$	1·3 × ·61

The astragalus, which is nearly entire, gives the following measurements:—

Transverse diameter of anterior portion	2″·5
Height of scaphoid facet	1″·55
Distance between the summits of the trochlear ridges . .	1″·5

The bone is coated, like the jaw, with hard crystalline stalagmite, and it exactly fits the lower end of a tibia said to have been found at a distance of 50 feet from it and at a much greater depth; but this was in a locality that had been previously disturbed. There can be little doubt that the two bones belonged to the same animal.

2. Eleven specimens occurred in the Flint-knife Gallery at distances varying from 1 to 46 feet from the entrance, and all at depths of from 9 inches to 5 feet in the third bed. Amongst these remains are two perfect phalanges, which, though differing somewhat in colour, fit together so exactly as to allow little room for doubt that they belonged to the same animal, although one was found 10 feet from the entrance at a depth of 3 feet, and the other at a distance of 46 feet from the entrance and at a depth of about 5 feet. Other bones worthy of note are:—1. The lower portion of a left humerus with the distal articulatory end nearly entire, and measuring in transverse diameter about 3 inches, with the least circumference of the shaft 5″. The shaft is broken across at about the junction of the upper and middle thirds, and the fracture, though ancient, is quite sharp, and the bone exhibits no mark of its having been either rolled or gnawed. 2. An entire left radius, 12″·6 long, with the proximal end 1″·8 × 3″·25 in the antero-posterior and transverse diameters, and the distal 1″·6 × 2″·8, with a least circumference of 4″·5, exactly fits the above humerus. As in the former case of the tibia and astragalus, these two bones, though found very widely apart, would appear to have belonged to one and the same individual. They are both, it should be remarked, deeply impregnated with manganesic oxide. 3. A left metacarpal, measuring 8″·5 in length, the proximal end 1″·35 × 1″·9, and the distal 1″·3 × 1″·7, with a least circumference of the shaft of 3″·7, and consequently corresponding in dimensions with those of a Horse about 13 hands high. The bone, though quite entire, and to all appearance not rolled by water action, seems to have been exposed for some time on the surface of, or partly imbedded in, the ground, as it is much weather- or sun-cracked, principally at one end. 4. Among the remains found in this part of the cavern are a pair of small metacarpals of the right side, obviously belonging to the same limb, one of which was met with at a distance of 3 feet from the entrance and at a depth of 42 inches, whilst the other occurred at a distance of 26 feet and at a depth of 33 inches—affording another instance, of which so many are presented in the cavern, of the separation of parts belonging to the same animal, which it is reasonable to believe must have been brought into some part of the cave whilst still connected by the soft parts.

3. In the West Chamber two specimens occurred at a depth of 13 feet in the third bed, or at the most usual depth for bones in that compartment. They were both marked with characters of the greatest antiquity.

4. In the South Chamber the only equine remains were four teeth, evidently belonging to the same animal, though to opposite sides of the upper jaw. The teeth are remarkably white, though more or less dendritic.

III. RUMINANTIA.

4 & 5. *Bos.*

Remains belonging to the genus *Bos* are not very numerous, and, with the exception of the teeth, most of them are very imperfect. Seven specimens occurred in the Reindeer Gallery, seventeen in the Flint-knife Gallery, and three in the West Chamber.

But these include only the clearly determinable specimens, and it is quite possible that there may be several others among the splinters and fragments.

In the Reindeer Gallery, with three exceptions, the bovine remains were all met with at a less depth than 12 inches in the third bed.

The exceptions are:—

1. A left metacarpal bone, which is entire, except that the distal articular end has been broken or gnawed off. Its extreme length, therefore, cannot be stated, but it measures from the highest point in front to the vascular opening at the lower termination of the anterior sulcus 7 inches; whilst the proximal articular end measures 1″·8 × 3″·2, and the least circumference of the shaft is about 5″. The bone itself is of a mottled grey colour, and the cortical substance when broken is of a grey hue from dendritic infiltration. The specimen, therefore, though apparently not so much mineralized as many of the others, must be regarded as belonging to an ancient period. It was found 24 feet from the entrance, at a depth of 6 inches in the fourth bed, "over which the third bed was 42 inches deep, and over this again the cake of stalagmite was about 6 inches thick." But it is added, "this ground had been broken by PHILP;" so that, notwithstanding the condition of the bone, which is by no means opposed to its occurrence at such a depth, some doubt may be entertained whether it was originally lodged at the level from which it was removed. 2. The second exception is also a portion of a cannonbone which has been split down the middle on each side, and has been much gnawed at either end, apparently by the Hyæna. The bone is of much the same size as the preceding, and it is in the same condition in other respects, or perhaps rather more mineralized. It was found at a depth of 4 feet in the third bed, together with two flint fragments (implements ?). 3. The third deep-seated specimen is a doubtful fragment of a humerus.

The specimens met with near or on the surface of the third bed consist of:—(1) A small fragment of a large metatarsal. (2) The third and fourth cervical vertebræ, of which the bone is of a light colour, with scarcely a trace of dendritic deposit, and covered with a thin layer of crystalline stalagmite. These two vertebræ, in fact, are in precisely the same condition as the Horse's jaw described above. They are both stated to have been found at a depth of 3 inches in the third bed, and at a distance of 85 feet from the entrance, although from their aspect it would seem likely that they should have been nearer the surface and in contact with the stalagmite. (3) A portion of the left maxilla with four molar teeth *in situ*. This specimen was found, as it would seem, on the surface of the third bed; but it presents no trace of calcareous deposit, and the condition of the bone and teeth, as respects colour and mineral impregnation, exactly resembles that of the two cannonbones above described.

This specimen is worthy of special regard. It is probably the jaw of a rather young animal, inasmuch as the two premolars which remain are very little worn. The species appears to have been about the size of the common Ox. The length of the series of two premolars and two molars is 4″·5, and the dimensions of the individual teeth are the following:—

2 pm	·9 × ·9
3 pm	·9 × ·92
1 m	1·35 × 1·10
2 m	1·40 × 1·12

The second premolar is peculiar in having a double columella, which is rather curious, since several other molar teeth were met with in the Flint-knife Gallery and in the West Chamber, all of which present the same peculiarity*. One of these, a third molar of the right side, in fact fits so exactly and corresponds in other respects so closely with the teeth remaining in the jaw, that one might almost suppose it belonged to the same set, were it not that it is very much more deeply stained with black. A left second upper molar, also found in the Flint-knife Gallery, and a third left upper molar found in the West Chamber, are furnished with the same double columella, and in most respects correspond so closely with the same teeth of the right side in the jaw, as almost to justify the supposition that they belonged to the same individual; they are, however, much more deeply stained and rather less worn.

The peculiarity referred to in these teeth is shown in Plate XLVI. fig. 11.

In the Flint-knife Gallery, besides the teeth above noticed, were found (1) another left third upper molar, considerably worn, and showing the remains of a single columella, and of a very dark colour; (2) a left third upper premolar, very closely corresponding with the same tooth in the jaw above mentioned, though of a deeper colour, and clearly belonging to the same set as the second and third molars of the left side already described. And together with this tooth, which was found at a depth of 5 feet in the third bed, was found a second milk-molar of the right side, and considerably worn.

The other remains, besides the teeth, found in the Flint-knife Gallery worthy of particular note are:—

1. A sixth cervical vertebra, which in mineral condition closely resembles the jaw and two cannonbones found in the Reindeer Gallery. It occurred at a depth of 28 inches in the third bed, and 19 feet from the entrance, in company with one of the molar teeth. The length of the body of this vertebra, measured in a plane parallel with the inferior surface of the body, is 3″·6, and the height of the posterior cup 1″·4; it is therefore of about the same dimensions as in the common Ox.

2. A second well-marked specimen is the nearly entire distal articular end of the radius of a much larger animal, and closely approaching *Bos primigenius*, if not identical with it. The antero-posterior diameter of this bone is 2″·2, and its transverse 3″·7. It is of a deep black colour, and has been manifestly gnawed by the Hyæna.

3. Several gnawed splinters of long bones, for the most part of the tibia, also of very large size, and having the muscular impressions as well developed as in *B. primigenius*, and consequently much more so than in *Bison priscus*.

The remains found in the West Chamber are, besides the tooth already mentioned, a fragment of the humerus and of the olecranon, and the neck of the scapula, all deeply coloured and gnawed by the Hyæna.

---

* The duplication of the columella appears to be common in teeth of *Bos primigenius*.

6. *Cervus* (*Strongyloceros*) *elaphus.*

Not more than ten or eleven specimens, referrible with tolerable certainty to the subgenus *Strongyloceros*, Owen, appear to have been met with in the Brixham Cave. It is far from improbable, however, that additional pieces may exist amongst the undetermined fragments and splinters.

With three exceptions these remains lay at an average depth of between 3 and 4 feet in the third bed, in the Reindeer and Flint-knife Galleries—the least depth being 9 inches, and the greatest about 8 feet, both in the former locality. Six of these specimens consist either of the basal portion of shed horns or of fragments (two) of round antlers. All these specimens present an appearance of great antiquity, being deeply coloured, heavy, and dense. The three exceptions, on the contrary, exhibit a comparatively more modern, or rather a less ancient aspect. One of them, a proximal phalanx, was found at the bottom of a "pipe," which penetrated 5 feet into the fourth bed in the Reindeer Gallery; whilst the others, consisting of an astragalus and a portion of the right maxilla with three teeth, were met with on the surface of, or immediately below, the stalagmite floor in the Flint-knife Gallery and South Chamber.

The character of the horns is well marked, and such as to leave no doubt of the subgeneric position of the species. They all appear to have been gnawed, and perhaps rolled; and they have all formed parts of naturally shed antlers of different sizes, varying in circumference immediately above the burr from 7 to a little more than 9 inches; they were consequently about the same size as the horns of the existing European species. The only other decidedly ancient bone from which any comparison can be drawn is a gnawed, or perhaps broken, and rolled right os magnum, nearly black in colour, and which measures 1″·6 × 1″·6.

The other remains, which occurred more superficially, comprise the phalanx above referred to as found in the "pipe," a nearly perfect astragalus, and a small portion of the right maxilla, containing the first and second molars *in situ*, and scarcely worn, in association with which was found a second upper milk molar, obviously belonging to the same jaw. This specimen is nearly covered with a thin layer of red crystalline stalagmite, beneath which the bone is of a dirty yellowish-white colour, and with hardly a trace of dendritic infiltration. The teeth, which, as has been said, have been scarcely brought into wear, measure:—

$\underline{1\ \text{m}}$	·98 × ·90
$\underline{2\ \text{m}}$	1·10 × ·90

The corresponding dimensions in a fine Scottish Stag are ·77 × ·81 and ·90 × ·91, and in a female specimen from Germany ·80 × ·80 and ·90 × ·85. In the British Museum there is a very fine collection of Strongylocerine remains from Grays Thurrock, amongst which two forms, very distinct from each other in size, but otherwise indistinguishable from *C. elaphus*, can be recognized. In the larger of these forms, the two teeth in question, in a specimen of the upper jaw (No. 20,277), which is rare as compared with the lower, allowance being made for their great difference in wear, are, at any rate at the neck, of precisely the same size as those from Brixham, whilst in the crowns they seem to correspond more nearly with the German specimen cited above. The second milk-molar, which is almost worn out, measures in its present state ·8 × ·7[*].

The astragalus, which was found in the Flint-knife Gallery 10 feet from the entrance on the surface of the third bed under the stalagmite floor, has a somewhat different aspect and condition. It is so light as to float on the surface of water, of a yellowish-white colour, with the slightest possible trace of dendritic deposit, and entirely free from calcareous incrustation or infiltration. It is superficially eroded on the more prominent points, apparently by rolling; and on one side there are two or three shallow triangular indentations, evidently ancient, such as might be produced by the canine teeth of a Dog or Fox. Its dimensions are:—

Extreme length	2″·5
Extreme breadth	1″·6
Extreme height	1″·5

The corresponding dimensions in the Stag above referred to, and in the female Deer, are,—in the Stag 2″·0, 1″·2, 1″·2, and in the Doe 1″·5, 1″·0, 0″·8. In the larger of the Grays Thurrock forms the astragalus in four specimens measures[†]—

2″·3 × 1″·45 and 1″·2.

The Brixham specimen consequently, as compared with either the existing or with the Grays Thurrock fossil forms, must be regarded as of rather large size. This, to a certain extent is in accordance with the indications afforded by the teeth; and I am disposed therefore, notwithstanding some differences in the condition of the bones, which may be accounted for perhaps by their different positions, to think that the fragment of jaw and the astragalus may have belonged, if not to the same individual, yet to one of the same size or breed. What relation this bone has to the horns and bones which lay at a greater depth I am unable to say.

---

[*] These teeth, however, are very far from equalling the dimensions which, it may be supposed, were presented by the corresponding teeth in *C.* (*Strongyloceros*) *spelæus*, Ow. If we calculate these dimensions from the size of the first lower molar in the jaw figured at page 471 of 'British Fossil Mammals,' which would appear to have been 1″·38 in longitudinal diameter, and assume that the upper and lower teeth in that species bore the same proportion to each other as they do in the Wapiti Deer, then the size of the $\underline{1\ \mathrm{m}}$ and $\underline{2\ \mathrm{m}}$ must, in *Strongyloceros spelæus*, have been 1·38 × 1·38 and 1·79 × 1·62, dimensions which seem to be enormous and scarcely credible. In the Wapiti Deer, the largest of the existing Strongylocerine species, the teeth in question measure 1·10 × 1·10 and 1·30 × 1·25, and in *Megaceros hibernicus* 1·20 × 1·12 and 1·20 × 1·12.

[†] Four astragali of the larger form afforded the following measurements:—

1. .... 2·25 × 1·4 and 1·2
2. .... 2·3 × 1·4 and 1·2
3. .... 2·3 × 1·45 and 1·2
4. .... 2·15 × 1·4 and 1·2

Mean .... 2·25 × 1·41 and 1·2

Four astragali of the smaller form:—

1. .... 1·85 × 1·1 and 1·0
2. .... 1·95 × 1·2 and 1·1
3. .... 1·85 × 1·15 and 1·1
4. .... 1·9 × 1·2 and 1·1

Mean .... 1·98 × 1·16 and 1·1

There are also numerous calcanea of the two forms, which stand in the same uniform relation to each other as regards size; and it is to be remarked that there are *no* intermediate sizes.

In fact the two forms of *C. elaphus*, if that be the species, from Grays Thurrock seem to occupy the same relative positions as *C. elaphus* and *C. barbarus* at the present time, both of which coexist in the Gibraltar breccia.

7. *Cervus tarandus.*

Next to those of the Bear, the remains of the Reindeer are by far the most abundant in the collection from the Brixham Cave. I have been able to determine about seventy well-marked specimens, besides which there are, without doubt, several more among the undetermined fragments.

They occurred in about fifty different localities in the Reindeer and Flint-knife Galleries and in the West Chamber, those from the two former localities, however, being by far the most numerous.

In the Reindeer Gallery about twenty-five specimens were met with, from the surface to a depth (in one instance only) of 8 feet in the third bed, and taken generally at a depth of a little more than 2 feet, and at distances from the entrance varying from 18 to 86 feet.

In the Flint-knife Gallery five or six out of thirty-five specimens were found lying on the surface of the third bed or immediately beneath it; some below, and others either on or protruding through the stalagmite floor. But deducting these superficial specimens, the average depth at which the others occurred was a few inches deeper than in the Reindeer Gallery.

Ten specimens were found in the West Chamber, and, as in nearly all other instances, the remains there met with occurred at a much greater depth, varying from 4 to 13 feet.

With the exception of the eight or ten specimens which were found lying on or near the surface of the third bed, and either upon or immediately beneath the stalagmite floor, the Reindeer remains all have a very ancient aspect—that is to say, they are deeply coloured, dense, and dendritic.

The superficial specimens above referred to, on the contrary, are light-coloured, dry, and porous; some incrusted with a thin crystalline stalagmitic deposit, others not. And with respect to these, it is a curious circumstance that several among them, though met with in different parts of the cavern, and at some distance as it would seem from each other, appear to be parts of the skeleton of one and the same young animal. The most noteworthy of these are:—1. The upper part of the cranium of a young Reindeer, on which are seen the two horn-bosses, and which was found together with the distal portion of the left femur, having the articular end nearly all gnawed off, and whose shaft 6 inches above the lowest part of the remaining outer condyle is 3″·7; and at the same spot were found four or five teeth. These specimens were found in the Reindeer Gallery 32 feet from the entrance, lying on the surface of the stalagmite floor. 2. The upper part of the left tibia, evidently corresponding with the above femur, but which was found in the Flint-knife Gallery 22 feet from the entrance, lying on the surface of the third bed. 3. Three other portions of apparently the same skeleton, or at any rate of an animal of the same age, are a portion of a cervical vertebra, which lay on the stalagmite floor in the Reindeer Gallery, 81 feet from the entrance, a fragment of a calcaneum, and the greater part of a metatarsal, which were deposited one on the surface and the other 3 inches deep in the third bed in the Flint-knife Gallery, about 10 feet from the entrance.

With respect to the older or, at any rate, deeper remains, few remarks are required. The form to which they belonged seems to have been of medium size; and most of the bones, but not all, exhibit undoubted marks of having been gnawed, most probably by the Hyæna. But of these more deeply deposited remains two exhibit the light colour and porous condition by which the superficial bones are distinguished: both are upper portions of the left radius, one of which occurred at a depth of 54 inches and 21 feet from the entrance of the Reindeer Gallery, associated with the astragalus and a tooth of *Rhinoceros* and the calcaneum of a Bear, all three of which presented the characters of great antiquity; the other was found by itself in the "Flint-knife Gallery," 45 inches deep in the third bed, and 53 feet from the entrance, but "amongst loose angular stones."

I have placed in the subjoined Table the measurements of some of the parts of different bones of the Brixham Cave Reindeer, contrasted with those of individuals of the existing Norwegian and American forms and some others, in order to afford an idea of the comparative dimensions of the species.

Comparative Dimensions of Bones &c. of Reindeer. (0″·01.)

Part.	Brixham Cave.	Norwegian Reindeer.	American Reindeer.	Les Eyzies.
Glenoid fossa	135 × 120	120 × 110	155 × 145	140 × 130
Distal end of humerus	190 × 180	185 × 170	195 × 215	
” ”	180 × 160			
Least circumference of humerus	350	297	335	
” ”	235			
Proximal end of radius	105 × 180	100 × 160	105 × 200	
” ”	95 × 162			
” ”	95 × 160			
Length of radius	920	870	1075	
Least circumference	290	235	330	
Distal end of metacarpal	90 × 170	80 × 150		
Acetabulum	120			
Distal end of tibia	115 × 150	115 × 145	135 × 180	
” ”	120 × 150			
” ”	120 × 155			
” ”	120 × 155			
” ”	120 × 150			
Distal end of metatarsal	90 × 170	85 × 150		
Calcaneum	390 × 115	340		
”	350 × 110			
Astragalus	180 × 110	170 × 105		
”	180 × 110			
Scapho-cuboid	120 × 130	..	..	120 × 135

8. *Capreolus capreolus.*

Not more than ten or twelve specimens of remains distinctly belonging to the Roebuck have been collected. They occurred in about equal numbers in the Reindeer and Flint-knife Galleries only; in the former at an average depth of about 10 inches, and in the latter of about 30. Its horizon, therefore, so far as can be judged from such scanty materials, would seem to be higher than that of the Red Deer. In the external appearance and general condition of the bones they would seem to be fully as ancient as those of any of the other animals; and though some are lighter and more porous than the rest, none can be regarded as decidedly modern. Several of the bones are quite perfect, whilst others exhibit signs of having been gnawed; and others again, if not most of the long bones, from their cracked and weathered aspect, would seem most probably to have lain exposed to the sun and weather before they were introduced into the cavern.

Among the remains of the Roebuck, the most worthy of note are:—

1. The lower end of a right tibia, with the articulation perfect, and measuring ·90 × 1·20, whose shaft appears to have been broken across about 4 inches above the end, the broken end showing signs of having been gnawed. This fragment, which is light-coloured and porous, though found at a depth of 42 inches in the third bed and 42 feet from the entrance of the Flint-knife Gallery, appears to correspond so exactly in size, colour, and general condition with a calcaneum met with, together with a proximal phalanx, in the Reindeer Gallery, 70 feet from the entrance, and only 2 inches deep in the third bed (where it was associated with numerous bones of Hare, Rabbit, and Fox, and the tooth also of a young Bear), that it is not unfair to surmise that they may have belonged to the same animal. 2. A beautifully perfect left metacarpal in similar condition. 3. An equally perfect right metatarsal, 8″·3 long, of rather darker colour, but still not very unlike the above. Both the last two bones occurred not far apart, and on or near the surface of the third bed in the Flint-knife Gallery. 4. Another right metatarsal, very fragile and deeply weather-cracked, was found, together with a portion of the pelvis, at a depth of 6 inches, and 76 feet from the entrance of the Reindeer Gallery.

IV. CARNIVORA.

9. *Felis (Leo) spelæa.*

Though scanty in number, the remains of the Cave-Lion are amply sufficient to show the existence of that species amongst the animals whose remains were found in the Brixham Cave. These remains, all of which present the characters of extreme antiquity, were, with perhaps two exceptions only, found at a considerable depth. The least depth at which a specimen undoubtedly belonging to *Felis spelæa* was met with was 48 inches in the third bed, and a distance of 83 feet from the entrance of the Reindeer Gallery; and it affords the only instance of the occurrence of the species in that compartment of the cavern. The specimen is a left outer incisor, very much worn; and in that respect, as well as in size and condition, exactly corresponding with the same tooth still *in situ* in a fragment of the maxilla found at a depth of 5 feet in the third bed, and

54 feet from the entrance of the Flint-knife Gallery. In that compartment of the cavern five indubitable specimens belonging to the Cave-Lion were met at the depth of about 5 feet, and all about 50 feet from the entrance. They consist of:—

1. A much-worn upper canine, exactly resembling the one figured in 'Reliquiæ Diluvianæ,' plate xxii. figs. 6, 7.

2. A portion of the right maxilla, with the third and fourth premolars *in situ*.

3. A similar portion of the left maxilla with the 2 pm and another portion of the same jaw with the third incisor *in situ*, all looking old and weathered; and the three portions appear without doubt to belong to one and the same individual.

4. A fifth proximal phalanx of the manus.

5. A fourth phalanx, probably belonging to the same individual. The former of these bones is very nearly entire, the latter is fractured at the distal end. Both, as I am informed by Mr. Boyd Dawkins, to whom I am indebted for the certain determination of these specimens, are remarkable for their comparative slenderness as compared with those which had previously come under his inspection, and also for the great depth of the dorsal pit immediately above the head of the bone. This is a character which I find varies a good deal also in the recent species, being sometimes almost wanting, and at others well marked; but I have seen no case in which it is so pronounced as in the Brixham fossils. Both of the bones are figured in Plate XLV. figs. 7 and 8.

10. *Hyæna.*

Next below those of *C. tarandus* in frequency are the remains belonging to *Hyæna*. They amount to about sixty in number, and were found distributed nearly equally in three divisions of the cavern, viz. eighteen in the Reindeer Gallery, seventeen in the Flint-knife Gallery, and twenty-one in the West Chamber.

In the Reindeer Gallery the average depth at which the bones of *Hyæna* were found seems to have been about 37 inches in the third bed, and the greatest depth about 9 feet.

In the Flint-knife Gallery the average depth was about 4 feet, and the greatest depth 5 feet 6 inches.

In the West Chamber the average depth was between 10 and 11 feet, but fully half of the bones there met with lay at a depth of 13 feet. No specimen referrible to *Hyæna* seems to have occurred above the stalagmite floor, nor more than four or five on or very near the surface of the third bed. These are:—three specimens met with in the Reindeer Gallery at a depth of from 9 to 12 inches, and at distances of 29, 39, and 50 feet from the entrance; whilst in the Flint-knife Gallery two specimens occurred at a distance of 7 feet from the entrance, one on the surface of the third bed in immediate contact with the stalagmite floor, and the other at a depth of 16 inches. The surface specimen, though presenting all the characters of the greatest antiquity, was associated, as it would seem, with more than 100 bones of the Rabbit, Hare, Birds, &c., all of which were in the usual condition of the superficial bones elsewhere. But the anomaly may probably be explained by the circumstance that in the same situation broken slabs of angular bone-breccia were also met with, leading to the conclusion that the ground must at some time previously have been disturbed.

The general condition of all the Hyæna remains proves their great antiquity; and it is to be remarked that very few among them exhibit any indication of gnawing, weathering, or rolling, and that amongst them are several perfect bones, in all probability belonging to one and the same animal. Another point also connected with these remains is the circumstance that, whilst amongst thirty-six specimens met with in the Reindeer and Flint-knife Galleries there is scarcely an entire bone, except one or two small bones of the feet, amongst the twenty-one specimens found in the West Chamber there are several perfectly entire long and other bones belonging to at least two or three individuals; and amongst these an atlas and two cervical vertebræ, which, together with other bones, apparently belonged to the same animal. It would seem, therefore, that this part of the cavern, which forms as it were the junction between the two principal galleries, was the chief point of refuge during life, or at any rate the chief receptacle of the remains shortly after death, of the Hyænas, the marks of whose teeth are so obvious in the numerous gnawed and splintered bones of the Rhinoceros, Elephant, Bear, Ruminants, &c. associated with them.

The bones and teeth clearly indicate several individuals of all ages, or from that at which the epiphyses of the femur and tibia were still ununited, up to one at which the canine teeth were almost worn away; but no certain trace of a fœtal or very young Hyæna is perceptible. All the teeth belong to the permanent series.

With respect to the species of *Hyæna* to which these remains belong, all I would here remark is that, so far as the bones of the extremities are concerned, it must have been of a size pretty nearly corresponding with the existing *Hyæna crocuta*, though perhaps a little lower in stature. As sufficient means of comparison between the skeleton of the Cave-Hyæna with that of the existing *H. crocuta* in the wild state (for the bones of animals that have been long caged are of little avail for the purpose) are wanting, it will be useless here to enter at any length upon that part of the subject; and I would merely remark that the quite perfect radius and tibia, shown in Plate XLV., do not appear to differ in any respect, either as regards dimensions or form, from the corresponding bones in the Spotted Hyæna*.

And with regard to the teeth, though more may be said, it is, I think, impossible to point out any characters, either in size or form, sufficient to distinguish the Spelæan from the Spotted Hyæna.

---

* As material for future comparison, the dimensions of some of the principal bones of the skeleton in the Cave specimens are subjoined:—

1. Atlas: antero-posterior diameters of dorsal and ventral arches, 1·10 and ·61; distance between the foramina in front 1·55.
2. Humerus: distal extremity, 1·60 × 2·15.
3. Radius: length 8·20 and 8·15; proximal end ·75 × 1·21; distal end 1·00 × 1·62; circumference of shaft (least) 2·10.
4. Acetabulum: diameter 1·12.
5. Femur: distal detached epiphysis 2·10 × 1·90; circumference of shaft 2·75.
6. Tibia: length 7·45; proximal end 2·00 × 1·90; distal end 1·50 × 1·00; circumference of shaft (least) 2·40.

In the subjoined Table I have given the mean, maximum, and minimum dimensions of the principal teeth in different species of Hyæna, from which it will be seen how very closely, in almost every tooth, the fossil Hyæna agrees with *H. crocuta* (*fera*), or, rather, as I should explain, with the larger variety of that species. Taking the individual teeth, it would seem that the upper canine is somewhat larger in the existing Hyæna, whilst the third premolar is a trifle less, its maximum size only coming up to the mean in *Hyæna spelæa*. The fourth upper premolar is considerably less, even its maximum size falling considerably short of the mean in the fossil form. The lower canine, again, like the upper, is somewhat larger in the existing species, though the difference is very slight. The first lower premolars are of nearly equal size in both, as are also the second and third; but the lower carnassial tooth appears to be sometimes a good deal larger in the fossil Hyæna, although its mean dimensions are but very little more.

Table showing the Mean, Maximum, and Minimum Dimensions of certain Teeth in different Species of *Hyæna*. (0″·01.)

	Canine.			pm 3.			pm 4.			$\overline{\text{Canine.}}$		
	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.
H. crocuta (*fera*)* ...	76×50	80×50	55×40	94×70	100×70	71×60	146×84	150×85	130×75	66×49	75×50	55×40
H. brunnea	67×50	70×52	65×50	93×63	100×67	90×60	142×85	150×90	140×82	72×50	75×50	70×50
H. striata	60×40	70×40	55×40	80×52	90×60	75×51	117×70	120×77	110×66	54×41	60×40	50×40
H. spelæa	74×46	......	......	100×73	......	......	160×87	......	......	71×52	......	......
H. (Brixham)	70×51	70×55	70×50	100×70	......	......	160×90	......	......	62×50	65×50	60×50

	$\overline{\text{pm 1.}}$			$\overline{\text{pm 2.}}$			$\overline{\text{pm 3.}}$			$\overline{\text{m.}}$		
	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.
H. crocuta (*fera*)* ...	63×44	70×48	50×35	85×60	90×62	70×50	91×52	95×50	70×50	120×50	120×55	100×40
H. brunnea	62×45	70×50	60×45	84×55	90×60	80×52	94×53	95×55	95×53	94×58	97×50	95×45
H. striata	52×32	60×35	47×30	72×44	75×48	70×40	78×43	80×45	72×40	81×40	85×40	77×40
H. spelæa	66×48	......	......	89×65	......	......	95×59	......	......	128×54	......	......
H. (Brixham)	61×46	65×48	60×45	90×61	90×65	90×60	92×58	95×60	90×55	125×53	132×52	120×50

On the whole, when we consider the fact that the dental differences between *H. crocuta* and *H. spelæa* are to the full as great, if not greater, than they are between the Lion and Tiger, I am hardly at present inclined to agree with Messrs. Boyd Dawkins and SANFORD in considering it proved that *H. spelæa* is merely "a variety of the Spotted Hyæna of South Africa"*. That it has no relation to *H. brunnea* or *H. striata* is at once seen from the comparison of the dentition; but that it necessarily represents the third existing species, though highly probable, cannot as yet be said to have been absolutely proved†.

---

* The minimum measures under *H. crocuta* are taken from caged specimens. There is no reason for supposing that the teeth are ever so small in the wild state.

It is rather remarkable that no coprolites of the Hyæna should have been met with in the cavern. It is impossible, with the minute care that was bestowed in the exploration, that such well-marked objects should have been overlooked. Is it possible that they had been washed away by currents of water insufficient to remove the more solid bones?

11–13. *Ursus.*

Of all the animal remains discovered in the Brixham Cave, those belonging to the Bear are by far the most numerous, and in some respects, more especially with regard to their distribution, perhaps of the greatest interest.

In the present, as in almost every instance, of the occurrence of ursine remains in caverns, the extreme variation in size and other characters of the different bones and teeth is so great as naturally to lead to the belief that they must have belonged to more than one species. Without pretending to decide or even to enter at large into the very difficult and important question of the distinctions between numerous species of Cave-Bears that have been described by authors, I will subsequently point out what appears to me to be the amount of evidence afforded by the Brixham-Cave ursine remains in favour of the view that they belong to more than one species, but will first say a few words with respect to their distribution in the cavern, general condition, &c.

1. *Distribution of the Ursine Remains.*—The number of specimens clearly determined is about 350 or 360; but besides these there are, in all probability, thirty or forty more amongst the as yet undetermined splinters and fragments. It should be remarked, however, as in some measure explanatory of this number, that it includes several collections, each composed of numerous bones of the skeletons of animals of various ages found lying together at the same spot. But if we take the number of separate stations in which ursine remains, as compared with those of the Reindeer and Hyæna, were met with, it will be even still more clearly seen how much those of the Bear predominate. The number of stations for each of these animals is:—

Ursus	71
C. tarandus	50
Hyæna	30

Of the specimens included in the above enumeration, about 116 occurred in the Reindeer Gallery, 210–220 in the Flint-knife Gallery, 26 in the West, and only 3 in the South Chamber.

---

* British Pleistocene Mammalia. Introduction, p. xlii.

† Further details concerning the cranial and dental characters of the existing Hyænas will be found in a paper published in the ninth volume of the Journal of the Linnean Society.

The mean level at which the bones were deposited in the Reindeer Gallery was about 28, and in the Flint-knife Gallery about 32 inches, whilst in the West Chamber they occurred, as would seem to have been the case with all the bones found there, at a much greater depth, or at about 110 inches. The mean horizon, therefore, of *Ursus* appears to have been about the same as that of the Reindeer, and a few inches above that of the Hyæna. It is also to be remarked that, as compared with the latter animal, a much larger proportion of its remains were found lying on or near the surface of the third bed, or even imbedded in the stalagmite itself.

Another remarkable circumstance connected with the ursine remains, and which has already been alluded to, is the number of instances in which bones obviously belonging to the skeleton of the same animal were found collected together in one spot.

Amongst the most remarkable of these collections may be mentioned one which, though not recorded in the "Register," was found, as we are informed by Mr. PENGELLY, "on the 29th July, 1858, upwards of 2 feet deep in the third bed, immediately north of the junction of the Reindeer and Flint-knife Galleries, in a small recess in the west wall of the former, and about 62 feet from the entrance, at a spot where the overlying stalagmite was about 4 inches thick." The bones in question, so far as they are exposed, include an entire left femur, the corresponding tibia lying in the natural posture it would assume in extreme flexion of the knee, and having the entire astragalus articulated to it in the natural position. Close beside these leg-bones, and in fact partly overlapping the astragalus, is the left radius; and attached to the specimen, when it first came under my notice, was the detached lower articular end of the same radius, with the scapho-lunar fossette entire. In a "Report of Progress in the Brixham Cave" drawn up by Dr. FALCONER in Sept. 1858*, this specimen is described as a "superb specimen of the bones of left hind leg, comprising the femur, tibia, and fibula folded together, with the patella and astragalus *in situ*." "These were found," the Report goes on to say, "near the Ebur chasm, and the other parts of the skeleton may be looked for when that portion of the cavern is dug up." And in a note given in p. 495 of the 'Palæontological Memoirs,' dated May 1863, Dr. FALCONER states that "all the circumstances connected with the entire leg of Cave-Bear (femur with tibia and fibula folded together, and ball of astragalus partly dislocated), and its position in comminuted shale, below the ochreous cave-earth and above a well-defined flint implement, were determined by me at Torquay and Brixham on September 2. I identified the remains and the flint, and drew the inference that the leg must have been introduced, with its ligaments at least fresh, after the flint had been introduced into the lower cave-deposit."

Subsequent examination, however, of this collection of bones, after the removal of the matrix in which they were imbedded, has shown that Dr. FALCONER was, to some extent, misled as to the true state of the case. The bone which, when very partially uncovered, he naturally took to be fibula, proves, when fully disclosed, to be the radius;

---

* *Antè,* p. 476.

and it would seem that what is described as the patella is in reality the detached end of the radius above noticed. Besides these, a further removal of the indurated clayey matrix has brought into view a large portion of a rib; and some other bones may not improbably still be concealed in the mass, which has been left intact in order to display the original juxtaposition of the remains.

This magnificent specimen is of special interest, as being that to which Sir Charles Lyell, in his work on 'The Antiquity of Man'*, and Sir John Lubbock, in 'Prehistoric Times'†, refer, but with respect to which they seem to have been not quite correctly informed. Sir C. Lyell speaks of the "occurrence at one point in overlying stalagmite of the bone of a Cave-Bear," and of the "discovery at the same level in the bone-earth, and in close proximity to a very perfect flint tool, of the entire left hind leg of a Cave-Bear." Although the argument sought to be strengthened by the circumstances thus recorded (of the contemporaneity of man with the Bear) is not materially affected by the correction, it is as well that this opportunity should be taken of stating the facts exactly as they stand.

The "bone" above referred to by Sir Charles Lyell as having been lodged in the overlying stalagmite is a very perfect humerus of a Bear of small size, which was found, in the position described, on the 30th July, 1858, at a distance of 67 feet from the entrance of the Reindeer Gallery, or at pretty nearly the same distance as the leg-bones; but it was, as has been said, completely imbedded in the stalagmitic floor, and consequently above the surface of the third bed, whilst the leg-bones lay at a depth of upwards of 2 feet in the clayey bone-earth; moreover, it was found at the opposite or east side of the Gallery. It should also be stated that the humerus differs from the other bones, not only in size, but very remarkably in its condition, which is nearly white, and it is wholly unstained by dendritic deposit, whilst the leg-bones are deeply coloured, very dendritic, and evidently of much higher antiquity. Nor does it appear that either the humerus or the leg-bones were found in close proximity to a flint implement. Three implements of the kind only can be referred to in speaking of these bones, viz. those numbered 1, 2, 3 in Mr. Pengelly's Report. Of these, Nos. 1 and 2 were found nearest the leg-bones. They were both found on the 29th July, 1858, 74 feet from the entrance, and 9 inches deep in the third bed, *i. e.* 12 feet south and 15 inches above the level of the leg-bones, or 7 feet south and 9 or 10 inches deeper than the humerus; they were, in fact, deposited immediately beneath the spot where the great antler was found on the upper surface of the stalagmite. The third flint implement was found the next day at a distance of 47 feet from the entrance, and 34 inches deep in the third bed.

A second instance of the same kind, and equally tending to show the probability that these remains must have lain almost undisturbed from the period of their sepulture, whilst still surrounded by the soft parts, or at any rate connected by ligaments, is afforded in the remains, evidently belonging to one and the same young Bear, which are recorded under Nos. XXVI. & XXIX. in the "Register." The remains comprised under No. XXVI. were found 3 feet from the entrance of the Flint-knife Gallery, at a depth of only 3 inches in the third bed. They consist chiefly of the right ramus of the lower jaw, with the permanent canine, though partially exposed by recent fracture of the bone, still wholly in germ, and with the crown of the penultimate molar just protruded from the alveolus. Together with this were several other teeth of the permanent and milk series, which, from their age and condition, undoubtedly belonged to the same individual, and a fragment of the right maxilla showing the $\underline{4}$ pm *in situ* and just emerged from the alveolus. Seven feet further in from the entrance, and lying on the surface of the stalagmite floor, was the opposite ramus of the same mandible, having the milk-canine still *in situ* and the permanent tooth completely concealed in the alveolus, though the second permanent incisor is fully protruded and the third is just making its appearance. Near the same spot was also found the shaft of a very young tibia sticking in the stalagmite, and which, there is every reason to conclude, belonged to the same individual as the jaws and teeth. These bones are all in the most fragile and delicate condition; and more especially is it to be remarked that the shell of bone covering the swollen germs of the permanent canines, and consequently in a much exposed part of the bone, is as thin as paper and as fragile as glass, or even more so. Nevertheless, except the injuries necessarily received by such fragile objects at or since the time of extraction, they appear absolutely perfect. They are of a light colour and very porous, in fact closely resembling the superficial bones generally. But it is a strange circumstance that among these comparatively modern bones of a very young Bear was found the ungual phalanx of an adult animal, nearly black in colour and a good deal worn or weathered, and presenting all the characters of the most remote antiquity.

---

* Third edition, page 100.

† Page 260.

A somewhat similar instance is afforded by the specimens included under Nos. CVII., CVIII., and CIX. of the "Register," all of which occurred from 10 to 16 feet from the same entrance, some lying on the surface of the third bed, and some imbedded in the stalagmite. Amongst these bones are the shafts of the right and left humerus, of both tibiæ, and a left ramus of the lower jaw (some of the milk-teeth still *in situ*); and the occurrence of this part, as well as of the two tibiæ, renders it probable that the bones associated with it all belonged to a second individual young Bear of about the same age as the one above described. All the bones are in the same light porous condition, though slightly dendritic and infiltrated with calcareous matter. The tibiæ are each perforated near the middle by a perfectly circular hole, about $\frac{1}{8}$ inch in diameter; these holes, from the appearance of the minute fractures round the edges, are evidently recent*. Together with these bones are associated a portion of the pelvis and the scapho-cuboid of the Roe, the slightly abraded and perhaps bitten astragalus of a very small Ox, and a fragment of a long bone, perhaps of the same, together with a small portion of the os innominatum of a young Hare. The bones of the Roedeer and Hare are in exactly the same condition, as regards colour and amount of dendritic infiltration, as those of the young Bear, and there is no reason to doubt their contemporaneity; but with respect to the bovine astragalus, as already stated, I am by no means so certain.

---

* From subsequent inquiry it appears that these holes were made for the purpose of fixing the bones on a board, in order to exhibit them with other articles.

A similar, though larger collection of ursine bones, but of those of a mature or perhaps rather of an aged animal, is recorded under No. CIII. The number of bones belonging to the same skeleton is in this instance between twenty and thirty, and they are all pretty nearly in the same condition as those just described—that is to say, of a reddish-white colour, exceedingly porous and friable. They were found in the Reindeer Gallery 10 feet from the entrance, or at about the same distance as the foregoing, but at a greater depth, as I should presume; though this is not very clear, as it is stated that they lay 30 inches deep in the *first* or uppermost bed. The collection includes:—the entire upper portion of the right femur and the upper part of the left minus the head, which was found detached and had apparently been gnawed or rolled, whilst all the other bones appear to be merely broken; a portion of the pelvis, with part of the acetabulum; several portions of the cranium and upper jaw, including the $\underline{1\ \mathrm{m}}$ and $\underline{2\ \mathrm{m}}$, both worn down nearly to the bottom of the crowns; a detached condyle of the lower jaw; and a portion of the right ramus, containing the canine and $\overline{3\ \mathrm{pm}}$ *in situ*, and exhibiting two small sockets for the $\overline{1\ \mathrm{pm}}$ and $\overline{2\ \mathrm{pm}}$, one close to the canine and the other immediately in front of the $\overline{4\ \mathrm{pm}}$. There is also a part of the left ramus, containing the $\overline{1\ \mathrm{m}}$ and $\overline{2\ \mathrm{m}}$, both worn down to the same extent as those of the upper jaw. The detached right upper and left lower canines and the detached head of the femur were also met with. From the size of the teeth and other bones, I should conclude the species to have been *Ursus arctos**.

A fourth remarkable specimen, but in which the bones exhibit a much greater degree of dendritic infiltration, and are, to all appearance, of older date, is recorded under No. XXIV., comprising about thirty bones of one and the same skeleton of a mature animal of gigantic size compared with the others already mentioned. In order to afford a good notion of the way in which an entire skeleton was probably left in one spot, it will be useful to mention the bones contained in this "find," which occurred 68 feet from the entrance of the Reindeer Gallery, and 33 inches deep in the third bed, or about a foot beneath and not more than 6 feet distant from the entire leg described above. The bones, however, do not belong to the same animal, but to one of much larger size. They include a nearly entire sacrum; large portions of the right and left ossa innominata, including the acetabula; a portion, about 9 inches long, of the right femur, wanting the head; a portion of the right tibia; portion of a scapula, ulna, and radius; nine vertebræ, some nearly entire; five or six large portions of ribs; an entire scapho-lunar bone and fragments of other bones; and mixed with them is what appears to be a fragment of a metacarpal or metatarsal bone of *Hyæna*.

On one of the ribs is a small notch, which Dr. FALCONER observes might have been made by means of a flint or stone implement. Of course this may be so; but upon close inspection I am inclined to think that it is not an incision or scratch at all, but a mere indentation by some blunt edge, which has simply depressed the soft texture of the bone without breaking the surface. The bottom and sides, therefore, of this very trifling mark appear rounded, smooth, and, under a magnifying-glass, exactly like the surrounding surface; but the appearance of antiquity which would thence attach to the indentation, were it really an incision, may, as it seems to me, be readily explained on the presumption of its being merely an accidental impression.

---

* One of the canine teeth of this specimen is figured in Plate XLVI. fig. 3.

Several other instances might be cited, but one or two more will suffice, to show that similar assemblages of bones were formed probably at the remotest periods of the history of the cavern. In one case between thirty and forty bones and teeth of a young Bear, together with a gnawed fragment of the scapula, several portions of the ribs, an astragalus, some metacarpal bones, a bone of the sternum, and teeth belonging to a mature animal, were found at a depth of 5 feet in the third bed, and at a distance of 46 feet from the entrance of the Flint-knife Gallery, intermixed with a tooth of *Felis spelæa* and bones and teeth of Hyæna, Rhinoceros, and Reindeer. The ursine bones and teeth are all dark-coloured and dense, and, in fact, in precisely the same condition as those of the other animals.

A second instance of the kind was afforded about 8 feet further from the entrance of the Gallery and at the same depth of 5 feet, where between thirty and forty bones, or fragments of bones, of a still younger Bear were found lying altogether, but, as it would seem, without mixture with those of any other animal. These bones present exactly the same ancient character, and they would seem to have been those of a sucking cub, or of one hardly beyond that stage of growth. They very closely correspond in every respect with those of a skeleton of a young Norwegian Bear in the collection of the British Museum, in which the middle permanent incisors of the upper jaw are in place though quite unworn, and the second and third milk-incisors still retained, together with the much-worn milk-canines. In the same jaw the first and third milk-molars, and behind these the first permanent molar, or $\underline{4\ \text{pm}}$, is nearly protruded; and behind that the first (second) molar is fully out, whilst the second or last molar is still wholly in germ, although its sac is very much enlarged. In the lower jaw the first and second incisors are fully out, whilst the third milk-incisor is still *in situ*, as well as the milk-canine and the first and second milk-molars. The point of the fourth premolar has just made its appearance, and behind that the first or antepenultimate molar is fully protruded, whilst the anterior half of the penultimate molar is visible above the alveolus, and the third molar is still wholly in germ. As the form of the ribs at this early period of growth appears to differ considerably from that which they subsequently assume (a difference which at first rendered the diagnosis of the bones very doubtful), the aid towards their identification rendered by this young skeleton in the British Museum has been invaluable. The difference in question consists in the young ribs being nearly all of them more or less square, with a rather deep groove on the anterior and posterior sides, and in the middle ribs having a deep fossa on the dorsal aspect, between the angle and the tubercle. Except in their size, these fragments of ribs bear a close resemblance to those of the Hare or Beaver.

2. With respect to the general condition of the ursine bones, little remains to be added to what has already been noticed in the preceding observations. In general terms it may be remarked that, with the exception of the instances in which the bones were found on or close below the stalagmitic floor or on the surface of the third bed, they are more or less dendritic; and in the great majority of cases they present the same characters of extreme antiquity as are shown in the bones of *Hyæna*, *Rhinoceros*, &c. It would appear, therefore, from this circumstance, as well as from the positions in which the ursine remains occurred, that they belong to all periods of the Cavern's history, from the earliest to nearly the most recent.

Many among the bones present marks of their having been gnawed, but the condition of a great many (and this is especially the case with those of the very young individuals) plainly shows that they were tranquilly deposited in or not far from the sites in which they were found. There can, in fact, be little doubt that amongst the Bear's relics, as with those of the Hyæna, some at least must have belonged to animals which habitually used the cavern as a place of refuge, and especially perhaps at the time of parturition and when they were nursing their young.

With respect to size and other particulars, the bones, as already observed, exhibit the extreme diversity which characterizes ursine remains in all situations, and which is as manifest in the bones of the larger existing species as it is among those of their fossil representatives. But, besides size, close scrutiny will detect in some of the bones certain differences, which must, I think, be regarded as indicative of more than mere sexual or individual peculiarity. Amongst the osteological characters which have been most generally looked for in the discrimination of fossil Bears, the size and form of the cranium and lower jaw have been more especially relied upon. The Brixham Collection affords no evidence of the former kind, and not much of the latter. With respect to the cranium, its form and size in existing species varies so extremely, not only between different races of the same species, but also between the sexes, that I am not inclined to place any very great importance upon it. As regards the lower jaw, however, the case is different. The greater convexity of the "inferior contour of the ramus" has been noticed as characteristic of *U. spelæus* by Professor Owen and other palæontologists, and it was regarded as of great value by Dr. Falconer among others. It appears to be a pretty constant character even in the oldest jaws; but it should not be forgotten that in other species the inferior contour is much more convex in the young jaw before the teeth are fully out than it afterwards becomes. The length of the diasteme is a second point often referred to; but this depends so much upon age and upon the proportionate size of the jaw itself, as compared with the teeth, as not, I think, to be of much importance. The presence of any of the small premolars is excessively rare in *U. spelæus*, whilst in *U. priscus*, Cuv. (*fossilis*, Goldf.), and *U. arctos* one or more of them, though never all three, are almost invariably found. When two exist, as is commonly the case in *U. arctos*, they are almost always the first and third, one being situated close to the canine and the other immediately in front of the $\overline{\text{pm 4}}$. But in two of the jaws in the Brixham Collection the two sockets are placed close together immediately behind the canine, leading to the supposition that in these cases it was the third and not the second premolar which was suppressed. There is, however, another character belonging to the lower jaw (which was, I believe, originally pointed out by Mr. WATERHOUSE) which appears to be of some value; this is the comparative thickness of the articular condyle. In all collections of fossil ursine mandibles they may manifestly be divided into two groups, from the difference in the proportions of this part; and as the difference in question is also accompanied, in the majority of instances, by certain differences in the teeth distinctive of *U. spelæus* and *U. priscus*, it may be taken as an additional specific character. The same difference, even to a still greater extent, is found between the mandibular condyle in the Lion and Tiger—the former having it very much thicker than the latter, even when the jaw itself and the teeth are of the same size. The thick condyle characterizes the lower jaw of *U. spelæus*.

As regards the other bones of the skeleton, I am not at present in a position to say any thing in detail. Many of them undoubtedly present differences which must be regarded as specific; but I am not aware that these distinctions have yet been assigned to the respective species. Amongst other bones in the Brixham Collection, differences will be observed in the humerus, more especially as regards the angle at which the supinator ridge descends from the shaft. Certain differences also may be noticed between two tolerably perfect unciform bones which are figured in Plate XLVI. figs. 9 & 10, and in the case of two astragali (one of which, however, is unfortunately very imperfect) which are represented in figs. 7 & 8.

But it is upon the teeth that we must chiefly rely in the distinction of species in fossil Bears, affording as they do the best and most easily appreciated characters. The characters of the teeth are derived partly from their relative and absolute dimensions, and in some of them more especially from their form. As regards the dimensions of the teeth, it is necessary to consider them not so much individually as relatively to each other in the same jaw. On this account the Brixham Collection, though rich in separate teeth, does not afford very abundant materials for their proper comparison *inter se*. I have placed in the following Table the dimensions of the various teeth occurring in the collection which are sufficiently entire for the purpose, which will give all the requisite information on that point, and will proceed to say a few words with respect to the forms of some among them which present the most marked characters.

Table I.—Dimensions of Teeth of Bears from the Brixham Cavern. (0″·01.)

	Can.	pm 4.	m 1.	m 2.	pm 4.	m 1.	m 2.	m 3.
	140 × 72	60 × 50	85 × 70	135 × 73	48 × 30	100 × 50	110 × 75	92 × 67
	135 × 80	65 × 56	90 × 70	155 × 80	58 × 31	100 × 50	105 × 63	98 × 70
	110 × 75	75 × 63	105 × 75	154 × 80	56 × 31	105 × 55	100 × 63	95 × 70
	135 × 80	66 × 55	110 × 60	153 × 80		110 × 55	110 × 66	80 × 65
	120 × 71			150 × 70		115 × 55	105 × 70	
	140 × 70			150 × 75		100 × 50	109 × 64	
	91 × 61			152 × 79		105 × 52	110 × 65	
	90 × 62						115 × 70	
	100 × 65						110 × 69	
	90 × 60						109 × 68	
	100 × 65							
	120 × 71							
	120 × 72							
	100 × 65							
	105 × 65							
	110 × 70							
	100 × 70							
	120 × 75							
	115 × 68							
	85 × 65							
	100 × 65							
	90 × 60							
	86 × 52							
Mean..	108 × 67	67 × 55	95 × 64	150 × 77	54 × 31	105 × 53	108 × 67	91 × 68

Canines.—The canine teeth in Bears appear to differ a good deal in size in the two sexes, as might be expected perhaps in animals not altogether carnivorous; and consequently, from the mere size of these teeth, within certain limits no very sure conclusions as to difference of species can be drawn. In the Brixham Collection, besides numerous incomplete or broken teeth, there are between twenty and thirty canines whose characters can be accurately determined. Their dimensions are given in the above Table; and as regards the types of form presented among them, the principal varieties are exhibited in figs. 1, 2, 3, 4 in Plate XLVI. From these it will be seen that they exhibit what may be termed three distinct forms, one distinguished principally by its small size, as shown in fig. 3, and one by its slenderness of shape, fig. 4.

If the forms of teeth here represented are compared with those given by M. Schmerling from the Belgian bone-caves, they will all be found amongst the latter. For instance, figs. 1 & 2 of the Brixham teeth appear to correspond very closely with M. Schmerling's figs. 1, 2, 3, 4, 5, 6; whilst fig. 4 strongly resembles his figs. 8 & 9, and fig. 3 his fig. 7. Whether, as M. Schmerling and many others suppose, these differences in the canine teeth are of specific value, and to what extent they are so, is by no means an easy question to determine; and I fully agree with him that sufficient attention has not as yet been directed to the dental, amongst other differences dependent upon sex. It is not at all improbable, therefore, that figs. 1 & 2 (Plate XLVI.) may represent merely the male and female canines of the same species, although it is just as likely they may be specifically different. But, so far as I have had any means of judging, it appears almost impossible that fig. 3 should also belong to the same; whilst if we regard the peculiar form of fig. 4, it seems difficult to believe that it also does not belong to a third. I am, however, inclined to the opinion that it may belong to the upper jaw of the same species as fig. 3, and also that the canine teeth in the present collection indicate the existence it may be of three, and certainly of two, distinct species of *Ursus*. In this view we might perhaps, though with doubt, refer fig. 1 to *U. spelæus*, and fig. 2 to *U. priscus*, whilst I have little doubt the two small teeth belong to *U. arctos*. This conclusion is supported by the numerical data given in the Table. The mean dimensions of the canine teeth found at Brixham are 108 × 67. Nine teeth are decidedly above this mean, whose average dimensions are 124 × 72; whilst six are as much below it, whose size is about 90 × 60. The dimensions of the intermediate eight are very uniformly 100 × 65. Among the teeth belonging to the first category there are four whose mean size is nearly 140 × 80, and four of 120 × 67. Now the former may fairly be referred to *U. spelæus*, whilst the smaller may represent either the female of that species or the large male of *U. priscus*. The teeth in the second category might in like manner be referred to *U. priscus*, whilst the smaller teeth in the third category may be assigned to *U. arctos*, in which species, from the measurements I have taken, the mean size of the canines may be given as 92 × 60. In *U. ferox* it is about 103 × 70, and in *U. maritimus* the same.

But it is in the molar teeth, and more particularly, perhaps, in those of the lower jaw, that we have to seek the most marked and distinctive dental characters.

These depend upon (1) the absolute and relative *dimensions*, and (2) on the form of the various teeth. As regards the former point, the materials that I have employed for comparison are contained in the subjoined Table, in which all the measurements I have been able to make or obtain of the molar teeth in most of the known and admitted species of recent and fossil Bears, including those from the Brixham Cave, are given. Upon these figures I will first offer a few explanatory remarks, and then proceed briefly to discuss the principal morphological characters.

In doing this, however, although most of the existing species are included in the Table, it will be needless for the present purpose to pay any particular attention to more than three or four, viz.:—1. *U. ferox*, Richardson, 1825 (*U. horribilis*, Ord, 1815); 2. *U. arctos*, Linn.*; 3. *U. maritimus*, Desm.; 4. *U. horriæus*, Baird.

The numerical data upon which I have gone in this inquiry are contained in the following Table †:—

---

* Under which I include *Myrmarctos Eversmannii*, Gray, *U. isabellinus*, Horsf., *U. syriacus*, Hempr. & Ehr., and all the other varieties of the European and North Asiatic Brown Bear, which have sometimes received distinct specific names, believing, as I do, that, regarded as subjects of palæontology, it would be impossible to distinguish among them.

† For the purpose of facilitating comparison the dimensions recorded in this Table are graphically represented in the "Odontograms" on Plate XLVII. These have been constructed on the plan described in Proc. Roy. Soc. 1870, vol. xviii. p. 544.

TABLE II.—Mean, Maximum, and Minimum Dimensions of the Molar Teeth of various Species of Recent and Fossil Bears. (0″·01.)

		$\underline{\text{pm 4.}}$			$\underline{\text{m 1.}}$			$\underline{\text{m 2.}}$			$\overline{\text{pm 4.}}$		
		Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.
1.	CUVIER's measurements.........	81×	82×	79×	115×	121×	110×	180×	188×	168×			
2.	SCHMERLING's measurements...	75×	82×	67×	114×	130×	102×	173×	196×	157×	59×	70×	47×
3.	All fossil forms. G. B..........	73×57	85×60	60×50	103×76	120×80	85×70	158×84	190×100	135×75	60×37	72×50	48×30
4.	Major fossil, *U. spelæus?*......	80×60	......	75×55	112×80	......	105×75	180×91	......	170×90	64×43	......	60×40
5.	Minor fossil, *U. priscus?*, &c.	63×52	66×55	......	90×71	95×70	......	147×79	155×80	......	57×31	56×38	
6.	*U. priscus.* B. M.*	65×52	......	......	90×75	......	......	135×75	......	......	56×30		
7.	*Ursus* from Brixham Cavern...	67×55	75×62	60×50	95×64	105×75	85×70	150×77	155×80	135×73	54×31	58×31	48×30
8.	*U. ferox*	62×47	65×55	60×36	91×67	92×70	90×60	150×73	150×75	148×68	51×30	52×30	50×30
9.	*U. arctos*..........................	61×43	65×50	58×43	83×61	90×63	80×60	126×66	140×70	120×60	45×28	50×30	42×30
10.	*U. isabellinus*..................	56×46	60×50	50×40	82×60	85×60	80×55	130×66	140×70	130×60	49×26	50×30	45×25
11.	*U. maritimus*....................	63×37	70×40	60×30	70×60	85×62	70×55	108×60	120×60	95×55	53×28	55×30	50×23
12.	*U. americanus*	47×34	50×40	45×30	70×53	72×60	69×50	100×56	110×65	92×50	37×20	40×21	33×20
13.	*U. torquatus*	52×36	55×40	50×32	80×60	85×60	75×60	117×66	120×70	110×60	41×23	45×25	38×22
14.	*U. labiatus*	47×39	49×40	43×38	67×46	70×46	65×46	75×40	80×41	70×40	40×20	41×21	40×20

		$\overline{\text{m 1.}}$			$\overline{\text{m 2.}}$			$\overline{\text{m 3.}}$			Molar Series.	
		Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Upper.	Lower.
1.	CUVIER's measurements.........	......	130×	......	115×	125×	106×	97×	102×	86×	376	
2.	SCHMERLING's measurements...	118×	133×	110×	118×	130×	106×	100×	121×	75×	362	395
3.	All fossil forms. G. B.	109×56	125×60	100×50	111×68	130×80	92×60	100×74	120×80	75×62	334	380
4.	Major fossil, *U. spelæus?*	114×58	......	110×55	116×74	......	108×70	118×84	......	100×70	372	412
5.	Minor fossil, *U. priscus?*, &c.	100×52	108×52	......	105×64	110×66	......	86×67	98×70	......	300	348
6.	*U. priscus.* B. M.*	100×50	......	......	95×60	......	......	75×65	......	......	290	326
7.	*Ursus* from Brixham Cavern...	105×53	115×55	100×50	108×67	117×70	105×63	91×68	98×70	80×65	312	358
8.	*U. ferox*	97×46	98×50	95×45	102×63	105×70	100×60	92×62	100×60	85×55	303	342
9.	*U. arctos*..........................	90×42	100×50	85×36	90×55	100×60	85×52	70×54	80×60	60×50	270	295
10.	*U. isabellinus*	85×42	90×45	80×40	92×60	110×60	80×60	76×60	80×65	70×55	268	303
11.	*U. maritimus*....................	86×38	95×40	80×35	81×45	85×50	76×40	61×47	70×50	50×40	241	281
12.	*U. americanus*	74×36	81×40	70×31	78×46	85×50	72×42	61×47	80×50	52×45	217	250
13.	*U. torquatus*	86×38	91×40	82×40	85×52	91×55	80×50	72×55	80×60	66×	242	284
14.	*U. labiatus*	67×37	70×35	65×30	60×40	60×40	60×40	44×	45×	43×	189	211

In this Table are given the mean, together with the maximum and minimum, dimensions of the molar teeth in nearly all the instances of different species to which I have had access, and they may be deemed sufficient to afford fair averages. It would have been satisfactory to have had more numerous specimens of *U. ferox*; but they are not attainable, so far as I know. Above my own measurements, I have placed in the two uppermost lines the mean measurements taken from those given by CUVIER and those extracted from M. SCHMERLING's invaluable memoir on the Belgian Caves. In the third line will be found the mean and other dimensions of the fossil teeth of all kinds that I have met with, and these include, of course, all the possible fossil species. Taking these mean sizes as the standard, I have separated all those teeth which came decidedly below the mean from those which as decidedly exceeded it. The results thus arrived at are given in lines 4 and 5. It thus appeared that the fossil ursine molars could primarily be divided into two very distinct categories, within one of which all the indisputable or typical specimens of *U. spelæus* were exclusively, or nearly so, included; whilst in the other, represented by the typical *U. priscus*, Cuv. (*fossilis*, Gldf.), fell a very considerable number now in the British Museum, the actual dimensions of which are given in the sixth line. In the seventh line are given, for the purpose of direct comparison, the mean dimensions of the Brixham molar teeth, as taken from the former Table. These numbers, it will be seen, do not greatly exceed those in the fifth and sixth lines, though they fall far short of those in the fourth. This is in support of the opinion that these teeth belong to more than one species; but at the same time the lowness of the numbers would serve to show either that there was a great admixture of very small with the large teeth, or that the greater part of them were of an intermediate size, corresponding pretty nearly with that of *U. priscus*. This I believe to be the case; but the evidence in support of the supposition is defective in some measure, as before observed, in the case of the Brixham teeth as compared with that of the others, in the circumstance that the dimensions are taken not from the successive teeth in the same jaws, but from isolated ones.

---

* These measurements are taken from M. GOLDFUSS's original specimen in the British Museum, which is probably that of a female.

In the eighth line will be found the dimensions of the various teeth in *U. ferox*, between which and those of the minor fossil form and of the typical *Ursus priscus* (GOLDFUSS's type) the closest correspondence will be seen to prevail, not in any particular teeth especially, but throughout the entire series, both upper and lower, as may be gathered at a glance from the two last columns in the Table, in which it is shown that the conjoined lengths of the upper molars is in smaller Cave-Bear 300 and in *U. ferox* 303, and of the lower 348 and 342, whilst the actual lengths of the molar series in *U. priscus* are 290 and 326 *. These coincidences appearing to me to be too close to be merely accidental, I compared side by side the typical skull of *U. priscus* in the British Museum with that of a fine and large specimen of *U. ferox* (No. 1137 ^{b}). In doing this I was unable to perceive any difference whatever between them, except the rather larger size of the recent specimen. In every essential particular they appeared to be identical; and I am consequently strongly inclined to the belief that it is impossible to draw a specific distinction between *U. priscus*, Cuv. (*fossilis*, Gldf.), and *U. ferox*. On the same occasion also I compared a tolerably perfect cranium from a peat-bog at Clonbourne in Ireland, and which is named in the collection *U. arctos* (No. 28906), and found that it exhibited all the characters of the other two, and was manifestly as much *U. priscus* as the typical specimen itself. In the museum of the Philosophical Society of Leeds there are also two Irish-peat crania, one named *U. spelæus* and the other *U. priscus*, though there may be reason to doubt whether the former is correctly so named†. The differences between them, including the width of the glenoid fossa, were precisely those which exist between *U. spelæus* and *U. priscus*; but unfortunately the teeth are wanting in both. Again, upon taking the measurements of the teeth in the fossil ursine remains from Grays, I find that the mean dimensions of those in three mandibles agree very closely with the sizes in *U. priscus* and *U. ferox*, as will be seen in the subjoined Table III., in which, for convenience, I have brought together only the mean dimensions of the molar teeth, adding those of the specimens from Grays.

---

* This coincidence will be still more readily appreciated upon comparison of the Odontograms, Nos. 12 and 13, Plate XLVII.

† With respect to that named *U. priscus* I entertain no doubt; but as the determination of the other has been made principally from its large size, it may possibly be the skull of a gigantic *U. arctos*, whose jaw, as represented by that from Manea Fen, is described by Professor OWEN as equal in length "to the largest specimen of the lower jaw of the *Ursus spelæus*." If so, the Fen Bear must have greatly exceeded any form of the existing Brown Bear, as Professor OWEN himself observes.

Table III.—Mean Dimensions of Molar Teeth in Fossil and some recent Species. (0″·01.)

	$\underline{\text{pm 4.}}$	$\underline{\text{m 1.}}$	$\underline{\text{m 2.}}$	$\overline{\text{pm 4.}}$	$\overline{\text{m 1.}}$	$\overline{\text{m 2.}}$	$\overline{\text{m 3.}}$	$\underline{\text{ms.}}$	$\overline{\text{ms.}}$
U. spelæus....................................	80×60	112×80	180×91	64×43	114×58	116×74	118×84	372	412
U. priscus?	63×52	90×71	147×79	57×31	100×52	105×64	86×67	300	348
U. ferox..	62×47	91×67	150×73	51×30	97×46	102×63	92×62	303	342
U. arctos	61×43	83×61	126×66	45×28	90×42	90×55	70×54	270	295
U. maritimus	63×37	70×60	108×60	53×28	86×38	81×45	61×47	241	281
Ursus (Brixham)............................	67×55	94×64	150×77	54×31	105×53	108×67	91×68	312	358
Ursus (Grays)	......	100×72	150×75	58×37	101×54	100×69	87×70	......	346

In these cases, again, we find a coincidence, as it seems to me, too close to be accidental; and I think further inquiry will demonstrate beyond doubt that the *U. priscus* is the same species as those above noticed from Ireland and Grays.

As regards the other species of Bear included in Table II., it is scarcely necessary here to make any remark. The numbers themselves will show pretty conclusively that, with the exception perhaps of *U. arctos*, none can be well confounded with either *U. spelæus* or *U. priscus*. In isolated teeth it will in many cases be quite impossible to distinguish between the smaller forms of *U. priscus* or *U. ferox* and the larger ones of *U. arctos*, in which species, as will be observed, the maximum size of the teeth equals, and in some instances exceeds, the minimum size of the same tooth in the others; whilst in many of the teeth there is very little, if any, difference of size at all. The most characteristic teeth with respect to size, as distinctive between *U. priscus* (*fossilis*, Gldf.) and *U. arctos*, appear to be $\underline{\text{m 2}}$, $\overline{\text{m 2}}$, and $\overline{\text{m 3}}$; but even in these cases the maximum size in *U. arctos* sometimes equals the minimum in the other. This circumstance is an exemplification, in addition to others which might be adduced, of the great tendency to variation exhibited in *U. arctos*, as has been already noticed. Its existence, however, shows the necessity in many cases of caution in the determination of a doubtful species from isolated teeth. Though I believe the mean dimensions, taken from a sufficient number of teeth *in situ*, may to a certainty be relied upon, mistakes may otherwise readily arise.

Having thus seen reason from the dimensions alone to refer *U. priscus* (*fossilis*, Gldf.) to *U. ferox*, and to believe that the greater part of the Brixham specimens belong to the same species, intermixed with a few of a larger size and several of a smaller, it will be interesting to inquire whether these conclusions are borne out by the forms of the more characteristic teeth. The most distinctive of these are, in the lower jaw, $\overline{\text{pm } 4}$ and m 3, and in the upper, pm 4 and m 2. In his very careful description of the Manea Fen jaw, Professor OWEN[*] notices that the lower last premolar in *U. spelæus* has "two distinct tubercles and a ridge developed from the base of the principal cone," whilst in the Manea-Fen jaw there was only the single cone, as in *U. arctos*. Subsequently, in speaking of *U. priscus*, he remarks that the same tooth also presents a second cusp on the inner side and a little behind the first. Now these characters appear to me to be very constant and of the utmost possible value. There can be no doubt, so far as I have seen, that in the true *U. spelæus* the last lower premolar has usually two cusps, and always one very distinct and, in some cases, a very large secondary cusp on the inner side, one of which is in front of the principal cone, and by which, irrespective of its size, that tooth may always be distinguished. In the typical specimen of *U. priscus* in the British Museum the last premolar, at any rate on the right side, of which I have a cast before me, has but an extremely faint indication of a second cusp, or rather tubercle, as it should be called in this species; but as the teeth in this specimen are much worn, the indistinctness may be owing to that circumstance. In a jaw of undoubted *U. priscus* from Gower a tubercular elevation is very distinctly situated also on the inner side of the tooth, but altogether behind the main cone; whilst in several of the Brixham teeth the small accessory tubercle in the same position is extremely well shown. In the only specimen of *U. ferox* in which I have had an opportunity of making the observation, the last premolar presents a distinct tubercle in the same situation, and the hinder talon, as it may be termed, is bitubercular. The next characteristic tooth in the lower jaw is the last molar. In *U. spelæus* this tooth, though varying, as is shown in the table, considerably in size, always presents more or less completely an oblong or quadrangular form with a deep sinus on the outer side, whilst in *U. priscus* it is always more or less triangular, and either not at all or very slightly notched on the outer border. It presents, so far as I have seen, the same general form in *U. ferox* and *U. arctos*; and it would in many cases be impossible, I imagine, to distinguish between these three species with respect to the shape of this tooth. There are five specimens of the last lower molar in the Brixham Collection, two considerably worn, the others very perfect. In all its shape is triangular, and altogether different from that presented by it in any specimen of *U. spelæus* that has come under my observation. One of the largest and smallest of these teeth are shown in figs. 5 & 6, Plate XLVI. The smaller may, and I believe does, belong to *U. arctos*, and I have no hesitation in referring the other to *U. priscus*.

In the upper jaw the differences in size are perhaps even more strongly marked than in the lower teeth; but, as regards their form, they appear to be less constant, and to exhibit less trenchant distinctive characters. The last premolar, though usually very much the larger in *U. spelæus*, presents no difference in form. In both it is tricuspid, and the relative sizes of the cusps appear to be much alike in both. In *Ursus arctos* I have noticed two distinct forms: one exactly resembles that in *U. spelæus*, *U. priscus*, and *U. ferox*, and is tricuspid, whilst occasionally the small inner cusp is entirely wanting, and the smaller hinder outer one is so much diminished in size as almost to give the tooth very much the form that it has in *U. maritimus*, in which the hinder cusp is very much less in proportion to the anterior. I am unable to point out any peculiarities between the different species beyond size in the penultimate upper molar; and with regard to the great tubercular molar, it presents such extraordinary diversities in size and form in one and the same species, that I have been at loss to seize any satisfactory characters in it. Speaking generally, as regards form, the last molar in *U. spelæus* is less contracted behind than it is in *U. ferox* (under which I include *U. priscus*) and *U. arctos*; but so many exceptions occur to this that the character becomes of little real value. Nor in minor particulars am I better able to discern any upon which it is worth while to dwell. But there is a sort of coarseness, as it may be termed, in the sculpturing of the tooth which appears to distinguish it from that of either *U. spelæus* or *U. arctos*. Most of the Brixham teeth have altogether the facies of *U. priscus*, and there is certainly none which can be referred to *U. spelæus*. But among the teeth is one so remarkable for its size amongst the others and for its form as to demand passing notice, although it probably has no more than an individual peculiarity. This tooth is shown in fig. 14, Plate XLVI. It is a left upper last premolar, fully as large as the mean size of that tooth in *U. spelæus*; and the inner cusp, instead of being single, is subdivided into three distinct points, of which the middle one is nearly as large as the usually single cusp occupying that situation.

---

[*] Brit. Foss. Mammals, p. 80. (It would be very desirable to have the measurements of all the teeth in this specimen.)

From the foregoing particulars, it would seem that the majority of the Brixham teeth exhibit, not only in their size but also in their form, the characters rather of *U. priscus* than of *U. spelæus*, of which latter species indeed we have, so far as I can perceive, extremely scanty evidence among the cave remains.

Although it is quite certain that the true *U. spelæus* has been by no means rarely met with in Britain, not only in caverns, but also, as it would seem from the Bacton specimen, in lacustrine beds, associated in both cases with the older extinct mammals, it appears to me, from what I have been able to observe in ursine remains from Ireland, that they are all referrible to what I should term *U. ferox fossilis*. No undoubted instance of the former existence of *U. spelæus* in Ireland has as yet occurred to me; and although it elsewhere most certainly coexisted with *U. priscus*, it appears, so far as I have been able to go into the subject, to be tolerably clear that the latter species, more especially towards the later period, has in this country been the more abundant of the two as a fossil, and has even survived to the present day in western North America under the form of *U. ferox*.

We may perhaps thus see some reason for imagining that there has been a very gradual succession in northern Europe of ursine species. Not to go further back, we find the gigantic *Ursus spelæus* of the German caverns, if not abounding, at any rate existing at an early period in these islands, if islands they then were. When it first became associated with *U. priscus* we have perhaps no means of knowing, but that in progress of time it gradually gave way to the latter seems to be highly probable. It survived, however, in all probability, sufficiently long to be associated also with *U. arctos*, which in its turn seems to have supplanted *U. priscus* (*U. ferox fossilis*). There is no reason to suppose, but quite the contrary, since we find that they were coexistent, that either of the smaller forms represents a degenerate descendant from the larger.

When the conditions of nature were such as to allow of the flourishing in these countries of the Cave-Lion and Hyæna, together with that of the gigantic herbivorous mammals, it is pretty clear that the Bear of that day to hold his own against such competitors must have possessed corresponding powers. But as these conditions changed, the change, in all probability, was to the advantage of a smaller and less powerful ursine carnivore. This form would flourish, as the Grisly Bear does at the present day, so long, and only so long, as the external conditions resembled those under which *U. ferox* now exists in North America. As that species is probably destined before very long to disappear, and perhaps to be wholly replaced by *U. americanus*, so in this hemisphere *U. priscus* became gradually replaced by *U. arctos*, a species which probably (in part from its less purely carnivorous habit, but in part also perhaps from its greater variability and consequently greater adaptability to circumstances) has become the sole representative of the ursine genus in the northern parts of the Old World.

That the Grisly Bear should have existed here at a remote period is of course no more strange than that *Ovibos moschatus* should at one time, and perhaps at the same epoch, have been a member of the British fauna. And their companion, the Reindeer, is another instance pretty nearly of the same kind, common though it still be to both continents. The Beaver also might be cited as an American inhabitant of Britain down to a very late period, were it certain that the American and European species were identical. The *Lagomys*, again, is at present as far removed from us, or nearly so, as *U. ferox**.

---

* Since the above was written, I have devoted a good deal of attention to the subject of the American Bears, and have come to the conclusion that in all probability there are two distinct species, or at any rate very distinct subspecies, included under *U. ferox* (*horribilis*, Ord)—a larger one found, as it would seem, mostly to the west of the Rocky Mountains, as in California &c., and the other and smaller more to the north and even to the east of that range, the former being the true Grisly Bear, and the latter the so-termed "Barren Ground Bear" (apparently the form named *U. horriæus*, Baird). Nor is it impossible that the same two forms might have coexisted at a former period in these islands.

14. *Canis vulpes.*

Seven instances occurred of the bones and teeth of the Common Fox, comprising nine specimens, five of which were met with in the Reindeer Gallery, and all but one on or near the surface, the exception being a carnassial tooth, which lay at a depth of about 2 feet. In one instance the upper and lower jaws were found intermixed with numerous apparently recent bones of the Hare, Rabbit, and Birds, and all the other specimens from this Gallery are evidently of comparatively recent date. Four specimens were found in the Flint-knife Gallery, one at a depth of 8 feet, another at 5 feet 6 inches, and the most superficial at about 3 feet. All these bones, in contradistinction to those from the Reindeer Gallery, are highly mineralized and obviously belong to a far more ancient period. In no other respect, however, is there the slightest difference between them.

It is remarkable that no specimen belonging to the Badger occurs in the collection. A canine tooth, which I had referred to that species, turns out upon further inspection to be the lower milk-canine of *Ursus* (*vide* No. XXVI.).

V. RODENTIA.

Innumerable bones of the Hare and Rabbit, of different sizes and of all ages, occurred in the Reindeer and Flint-knife Galleries, for the most part on or near the surface of the third bed or in the stalagmite floor. The only marked exceptions to this are in "find" No. XCII., in which the tibia of a young Hare occurred at a depth of 3 feet in the Reindeer Gallery, but apparently in the same condition as the more superficial bones; and in No. LIV. numerous bones were met with "amongst loose stones with little earthy matter," at a depth of 4 feet in the Flint-knife Gallery. The other rodents whose remains are found in the collection, and which occurred apparently in the same superficial situations, are at least two species of *Arvicola* and, the most interesting of all, a fragment of the cranium (including fortunately the entire maxilla and all the teeth but one) of *Lagomys spelæus*. This specimen (of which a figure is given in Plate XLVI. figs. 12 & 13) was found, together with numerous bones of the Polecat, Hare, Rabbit, Water-rats, Sorex, &c., in the Reindeer Gallery, 110 feet from the North Entrance, lying on the surface of the third bed. It differs in no respect in appearance from the other bones with which it was associated, and, like most of them, is slightly dendritic.

VII. Mr. Evans's *Remarks on the Worked Flints found in Brixham Cave.*

Of the fragments of flint of various sizes discovered in the Brixham Cave, and nearly all showing, in a greater or less degree, traces of human workmanship upon them, thirty-two have been submitted to me for examination.

They have for the most part undergone great alteration in their structure, having become white, absorbent, and brittle, in the case of the thinner flakes throughout their entire substance, and in the larger pieces to a considerable depth from the surface, if not, as appears to be the case with the largest of all, throughout. Though much softened in texture, the surface retains in some instances a bright porcellaneous glaze. On several there are portions left of the original surface of the flints, which appear to have been derived from the chalk. In one instance this original external surface is much battered, as if the block of flint had been exposed for some time upon the sea-shore before it was picked up in order to be utilized by man.

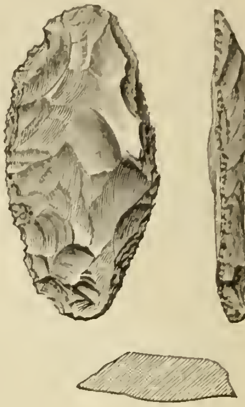
The following is the description of the more remarkable specimens, and of the circumstances under which they were found. The numbers are those used by Mr. Pengelly in the 1st column of his Table IV. (p. 494):—

No. 1. Portion of a flake, $2\frac{3}{4}$ inches long and $1\frac{1}{4}$ wide, the ridge side with three facets for about one third of its length, one of which ceases abruptly, while the others are continued to near the point, where they intersect the natural crust of the flint. The flake is obtusely pointed, and truncated at the butt-end, the part at the bulb of percussion having been broken off; it bears evident marks of wear at the truncated end, the edge being quite worn away. Both the side edges have also been much used. This instrument was found near the junction of the "Reindeer Gallery" and the "Flint-knife Gallery," at a depth of 9 inches in the loam bed, and just under the great antler.

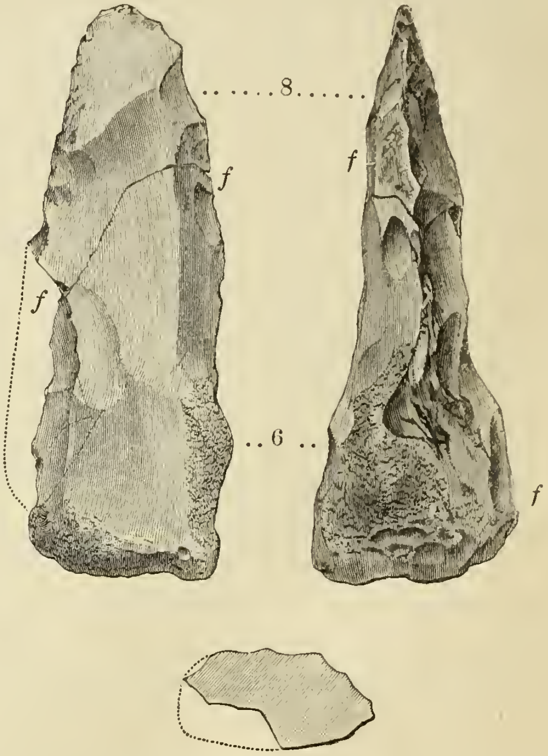
No. 4. Broad, irregularly shaped flake, $2\frac{3}{4}$ inches long, and in one part nearly 2 inches wide, but tapering to a rounded point. Three principal facets on the ridge side. The edges in several places have been worn away by use. About halfway along is a rounded notch, apparently produced by scraping some cylindrical object. (It is worth while to notice that a portion of a small cylindrical pin or rod of ivory was found in the cave.) This flake was found at a depth of 2 feet in the loam bed in the "Reindeer Gallery," 37 feet from the "North Entrance."

No. 5. Broad-ended flake $2\frac{3}{4}$ inches long, the ridge formed by two facets, with a third transverse facet at the broad end. This flake has been chipped or jagged along one edge, apparently by use, while the broad rounded end is so much worn away, in all probability by scraping some hard material, as to give the implement almost the character of the "grattoirs" of the French caves. These evidences of this extremely simple instrument having been designedly formed, and of its having been employed for cutting or scraping purposes, are most clear and satisfactory. It was found in the loam bed in the "Flint-knife Gallery," at a depth of 10 inches, and 19 feet from its eastern extremity, where it joins the "Reindeer Gallery."

No. 7. Implement of an elongated oval form, $3\frac{1}{4}$ inches long and $1\frac{3}{4}$ inch broad in the widest part, and about half an inch thick. It has been made from a large flake or splinter of flint with an approximately flat face, showing strongly the curved and waved lines of conchoidal fracture, and has been shaped by a succession of blows given in such a manner as not to injure the flat face, but to produce a more or less bevelled scraping or cutting edge all round. Some parts of this edge seem to present appearances of wear by use. In general character this implement resembles that of a boat-shaped form discovered by M. Lartet in the cavern of Aurignac, but it is not so neatly or symmetrically finished; at the same time it is more carefully chipped than an implement of nearly similar form from the valley gravel of the Lark, at Icklingham, Suffolk, which is in my own collection. Closely analogous implements occurred in the cavern of Le Moustier, in the Dordogne, explored by Messrs. Lartet and Christy (see 'Reliquiæ Aquitanicæ,' A. pl. iii. fig. 1). It is shown in the figure on the scale of one half.



Nos. 6, 8. Round-pointed implement of a lanceolate form, about 6 inches in length and $2\frac{1}{2}$ inches in diameter at the butt-end, which is roughly cylindrical. In general outline it closely resembles the spear-shaped implements from the valley gravels of France and England.



The point is symmetrically chipped, but the original surface of the flint has been left over the greater part of the butt-end, which is more squarely truncated than is usual with chalk flints, but is well adapted for being held in the hand. The implement has had the pointed end broken off by an irregularly diagonal fracture (f) rather more than half way along it, and the butt-end has subsequently split up lengthways with what might be called a "faulted" line of fracture, and about a quarter of it has been lost. The fractures are evidently of very ancient date; but what is most remarkable is that the butt-end (6) was found 12th August, 1858, 3 feet deep in the loam bed in the "Flint-knife Gallery," 27 feet from its eastern extremity or junction with the "Reindeer Gallery," while the point (8) was not found until 9th September following, 3 feet 6 inches deep in the loam bed in the "Pen Gallery," and 14 feet from its entrance or its junction with the West Chamber. It was not until some time afterwards that it was discovered that the two fragments fitted each other and that the true character of the implement was seen. It is shown in the annexed woodcut (p. 550) on the scale of one half linear*.

No. 9. Lozenge-shaped implement, 3½ inches and 2 inches in extreme length and breadth, and ½ inch in greatest thickness. One face of the lozenge is nearly flat, and two of the sides subtended by the longer axis are nearly straight and quite obtuse, while the other two come to a sharp edge. The outline of one is curved inwards, and the obtuse angle of the lozenge is rounded; there is a small portion of the original crust of the flint at one point. The sharp edges are considerably worn away by use; there are also marks of wear along the obtuse edges. This implement was found at a depth of 7 feet in the loam bed in the West Chamber.

No. 10. Fragment of a rounded block or pebble broken off by a single blow; the fractured surface is nearly flat, of ovate form, 3 inches long and 2 wide. It has a conical protuberance where the blow was given to produce the fracture. The rounded side has a waterworn appearance, as if the flint had been found on the sea-beach. The edge is chipped away, but whether by use or not it is impossible to say. This flint was found 11 feet deep in the loam bed in a fissure crossing the West Chamber.

No. 11. Short fragment of a flake, 1¼ inch long and 1 inch wide, the flint much decomposed. It bears no distinct marks of use upon it, and was found in the West Chamber at the depth of 6 inches in the "Gravel Bed," and 8 feet deep in the total deposit of loam and gravel.

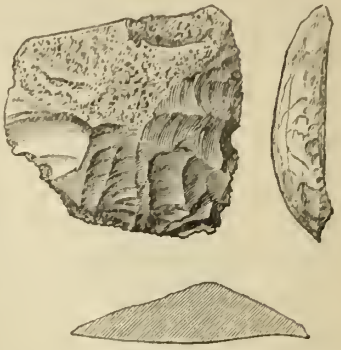
No. 12. Portion of a narrow flake, one edge of which has been lost owing to the flake having split longitudinally; what remains is 2½ inches in length, about ½ inch in width, and ¼ inch in thickness. The flake appears to have had originally three principal facets on the ridge side, but has been trimmed into a nearly semicircular outline at the butt-end; it bears slight but not very distinct traces of use or wear. This also was found in the "Reindeer Gallery," 35 feet from the "North Entrance," and 2 feet 9 inches in the loam bed.

No. 13. Angular fragment of flint of irregular obtusely pyramidal form, the base of the pyramid being a trapezium, the average length and breadth of which is 1¾ inch by ⅞. Most of the edges at the base are chipped away by wear or use. This very rude instrument was found in the "Reindeer Gallery," 26 feet from the "North Entrance," lying on the gravel bed and beneath a deposit of 7 feet, viz. stalagmite floor and cemented angular stones 3 feet, and cave loam 4 feet.

No. 27 ?. Irregularly shaped subangular flint pebble, somewhat pear-shaped in form. On one face the surface consists principally of the natural crust of the flint, and that of the other appears to be due to some natural fracture; so that in this case, unlike all the others, there is no evidence of the form being due to human agency. Most of the salient points, however, are battered and bruised; and though some of this may be due to the pebble having been exposed to the action of the waves on the sea-shore, yet, from the excessive battering of some of the angles, it seems probable that it may have served as a hammer-stone, simply held in the hand.

---

* By permission of the Committee, Nos. 6 & 8, 7, and 29 were figured by Mr. Evans in his 'Ancient Stone Implements of Great Britain,' and the above woodcuts are reproductions from that work. The other specimen (4) figured by Mr. Evans has since been found to be a surface specimen placed amongst the others by mistake. Mr. Evans had noted that it closely resembled some of the "scrapers" found on the surface of the soil and belonging to a more recent period than the Cave specimens (*l. c.* p. 470).



No. 29. Fragment of a large broad flake showing on its convex face a portion of the original crust of the flint. It is $2\frac{5}{8}$ inches in extreme width, and appears to have been originally of an approximately oval outline, but has lost one end by a straight fracture, where the flake was 2 inches wide. This end appears to have been broken off in ancient times after the rest of the instrument had been chipped into shape. The fracture at the other end is more irregular and existed before the completion of the tool, as several flakes have been removed from its convex face by blows administered on the fractured surface. One side of the flake has been trimmed by chipping, first boldly, and then more minutely, to a segmental bevelled edge much resembling in character that of some of the large "side scrapers" from the cave of Le Moustier in the Dordogne, like that engraved in the 'Reliquiæ Aquitanicæ,' A. pl. v. fig. 2. The edge presents the appearance of having been used for scraping some hard substance. This instrument was found 9 feet deep in the gravel of the West Chamber.

Implements of the same character occur occasionally, though rarely, in the old river-valley deposits.

?. Broad flake, $2\frac{1}{2}$ inches long and about $1\frac{3}{8}$ wide; the ridge side formed with two facets, but a portion of the ridge at the butt-end, or that at which the blow was administered to dislodge the flake from its parent flint, removed; the other end of the flake thick and truncated. This flake shows signs of use along a part of one of its edges. The other edge has been broken off, the flint being much decomposed, and the flake itself broken into three pieces.

The remaining specimens consist either of flakes, more or less perfect, or of splinters and rough fragments of flint, by far the greater part bearing evidence of having been artificially produced, inasmuch as one or more of their faces show the conoidal eminence or "bulb of percussion" as it was termed by the late Dr. FALCONER, or the corresponding depression, where the blow was administered by which they were fashioned. Some of the splinters are very small; and yet one of them, only $\frac{3}{4}$ inch by $\frac{5}{8}$ inch, shows the worn edge resulting from its having been in use as a scraping-tool.

The general result of the examination is that the worked flints from the Brixham Cave are found to present analogous, and in some cases almost identical, forms with those discovered in the ancient river-gravels and in other caves associated with the remains of animals now extinct, and that many of the implements prove not only to have been made by man, but to have been actually in use for cutting and scraping purposes before becoming imbedded in the cave-loam; while from nearly the whole presenting some signs of human workmanship or use upon them, it is evident that their presence in the cave must, in some measure, be due to human agency.

VIII. *General Conclusions respecting the Cave.*

The main object of this investigation is necessarily to put on record, in a form available for future examination, information of that special and exact character which, from the costly nature of the work and the variety of subjects connected with it, places it generally beyond individual research. It could not, in this case, have been carried out but for the liberal and timely assistance of the Royal Society and the cooperation of several members of the Committee, each taking a separate department. The able papers accompanying this Report describe in minute detail the structure and contents of a new and unexplored bone-cave. As before mentioned, the questions of theory will be restricted to those alone which are suggested by the local nature of the phenomena, some of which have, however, an important bearing upon the general question of ossiferous caves.

All observers agree that the cave follows the course of the two lines or planes of joint traversing the limestone rock, and that the galleries forming the cave have been excavated or worn along these lines of joint by the slow and prolonged action of water. Mr. Pengelly further points out that two sets of side grooves extend through the length of the cave with a dip inwards to one point, whence he infers its action at two successive levels, and that "each pair of grooves seems to be distinctly referable to a stream of fresh water which was not subject to great floods, and which flowed constantly from the West Chamber through the Flint-knife and Reindeer Galleries to the Steep Slide Hole, and the bottom of which was successively on the plane of the lower margins of the grooves themselves; while another stream came in at the road entrance and flowed to the same Hole."

Mr. Bristow, on the other hand, inclines to attribute some portion of the formation of the cave and the introduction of the shingle to marine action, at the time when the land was lower, and when, by the same marine action, the present valley was being excavated; and he observes that "the grinding-action of the waves and shingle may have assisted in widening a preexisting fissure and joint in the limestone, and have tended materially to increase the dimensions of those parts of the cave which were being formed by atmospheric influences, coupled with the flow of water resulting from the filling and emptying of the cave at every change of tide;" and in his communication to the Committee he points to the fact that the "pebbles of quartz, rounded fragments of the slate rocks of the district, &c. (forming the pebble bed in the cave) are precisely similar in character and appearance to those forming the raised beach visible on the neighbouring coast, as well as to the shingle on the shore of Mudstone-Bay sands north of Brixham." Mr. Pengelly considers that, in the case of the side grooves just referred to, "the tides and waves could not have allowed the preservation of levels so restricted," and that in confined spaces like the narrow galleries of a cavern, the waves of the sea would have arranged the materials differently to what they would on an open beach. There is an entire absence in the cave-shingle of shells, whether marine (such as would prove the presence of the sea) or freshwater (such as might be introduced by the action of a running stream). Fragments of the former would have been more likely to have been preserved than those of the latter, although there are many cases in which, in well-marked sea-beaches, there is an entire absence for considerable distances of any shell-remains. The bed of cave-earth which covers the shingle to a depth of several feet is attributed, both by Mr. Pengelly and Mr. Bristow, to subaërial action; but the former considers it to have been chiefly carried into the cave by running water, whereas the latter considers it mainly due "to the erosion of the limestone in which the cave is formed; that is to say, when the calcareous portion was dissolved and carried away, the insoluble portion was thrown down and left behind as a red mud forming the loam in question." The quantity of insoluble residue is, however, seemingly too large to be accounted for by the solution of the limestone removed in the formation of the cave, even including that of the fissures overhead, as the depth from the surface of the ground does not exceed 30 to 40 feet, and the fissures are close or nearly so. It is most probable that the greater part of the cave-earth was carried in by water from the exterior. Mr. Pengelly is also of opinion that the bones so numerous in the cave-earth were likewise drifted in from the exterior by the action of water; while Mr. Bristow considers that "the bones are for the most part those of animals which were carried into the cave to be devoured by the beasts of prey whose lair it may have been, or they may in some cases have fallen through fissures extending to the surface."

Mr. Pengelly supports his view by reference to the wear of many of the bones, the absence of coprolites, and particularly by the position and arrangement of the bones and stones, all of which (except those in the West Chamber) were lying lengthways, following the direction of the galleries, implying thereby "that the materials of this deposit were introduced and arranged by water flowing constantly in one direction."

But it is difficult to suppose this to have been the sole cause; for a large proportion of the bones are little or not at all rolled, very many of them are gnawed, and a few limbs have been found entire, while several others were, in the opinion of Mr. Busk, introduced with the flesh on them, although the bones were afterwards scattered. These facts seem to point to the cave having been inhabited by animals at some time or times. The absence of all traces of coprolites is not sufficient evidence to the contrary, as in a cave so subject to the irruption of water, the residence of the predatory animals could not have been prolonged, and their droppings may not have been placed under conditions favourable to their preservation. Even without rolling, the fractured edges of the bones also would often, like the angular fragments of limestone, be apt to lose their sharp angles by the solvent action of the water so long continued or by weathering.

Of the 669 bones (omitting the 152 teeth) examined and arranged by Mr. Busk, 67 are stated to be gnawed. But this refers only to the strongly marked cases; for, speaking of the bones of the Rhinoceros, Mr. Busk says, "most of the bones showed traces of gnawing by Hyænæ;" and he makes the same remark respecting the bones of the Reindeer. A certain proportion of the bones of the older Bears were in the same condition, as also were a considerable number of the undeterminable fragments of bones. Referring again to the bones of the Rhinoceros, Mr. Busk remarks that "some are very perfect and have no indication of having been rolled by water;" and he repeats the same observations in speaking of the state of the bones of the other animals. This condition of the bones is hardly compatible with their having been carried in by water, but is in accordance with the conclusion Mr. Busk has independently arrived at with Mr. Bristow, and which agrees with our own, that the cave must at one time have been a place of resort to Hyænæ, by whom most of the remains of other animals were brought in, often in the state of entire limbs surrounded by their soft parts. He is further of opinion that at a later period of the cave it was used as a place of refuge and at times of parturition by the Bears, as the bones of very young animals, sometimes mere sucking cubs, are often found together in heaps, and are neither rolled nor gnawed. Of very young Hyænæ there are no traces.

At the same time Mr. Busk mentions a left metacarpal bone of horse "quite entire and not rolled, which seems to have been for some time exposed on the surface, or partly imbedded in the ground, as it is much weathered or sun-cracked, principally at one end;" and he notices the same appearances on some other bones, leading, as he considers, to the inference that some portion of the bone-remains had been exposed to the open air on the surface of the ground, and afterwards washed into the cave by the action of a stream of water.

The dispersion of the bones of the same limbs in different parts of the cave did not escape the notice of Mr. Pengelly, and he accounts for the fact by their separate introduction and transport to variable distances into the cave by the stream; but the cases in which Mr. Busk has recognized an original connexion between the bones of the same animal in different and distant parts of the cave are sufficiently numerous, and their general condition is so alike and irrespective of position, that it is, we conceive, taking all other considerations into account, more probable that the limbs were, as he supposes, carried in entire, and that, as they were devoured, the bones were dispersed by the animals themselves through different parts of the cave.

The total number of bones found in the cave amounts to 1621; but of these as many as 691 belong to birds, rodents, and other small animals, which with few, if any exceptions, were brought in at a comparatively recent period, leaving 930 specimens belonging to the old cave-animals proper. Of these 669 have been determined by Mr. Busk, and 261 were in such a fragmentary state as not to be determinable. The number of species has proved more restricted than was anticipated, and the remains of only one Elephant and one Rhinoceros, both the common Pleistocene species, have been found. But though the species are limited in number, an addition has nevertheless been made to the cave-fauna of an unexpected and very interesting nature. Mr. Busk has determined the presence of two, and probably of three, species of Bear, viz. *Ursus priscus*, *U. arctos*, and more doubtfully *U. spelæus*, the first named (which Mr. Busk was led, in this case for the first time, to identify with the *Ursus ferox*) being by far the most abundant. It would thus seem that, in addition to the Musk-Ox, whose remains have within the last few years been discovered in the quaternary beds of this country and in the north of

France, the Grisly Bear, an inhabitant of the Rocky Mountains and other parts of North-western America, should also be added to the list of the old cave Mammalia of Europe.

This important determination has a bearing beyond the local case of the Brixham Cave, as Mr. BUSK considers there is reason to believe that many of the Bear-remains found in caves in this country and on the Continent and referred to *Ursus priscus* belong in fact to *Ursus ferox**. The presence of another small North-American animal has been ascertained, viz. the Lemming; and though its remains were found very near the surface, it has been met with elsewhere in association with Pleistocene Mammalia.

Excluding the more doubtful smaller animals†, the list, as determined by Dr. FALCONER and by Mr. BUSK, of animal remains found in the Brixham Cave consists of:—

			Number of determined specimens.
1.	*Elephas primigenius*	Mammoth	11
2.	*Rhinoceros tichorhinus*	Tichorhine Rhinoceros	67
3.	*Equus caballus*	Horse	30
4.	*Bos primigenius*?	Great fossil Ox	28
5.	—— *longifrons*?	Small fossil Ox	
6.	*Cervus elaphus*	Great Red Deer	12
7.	—— *tarandus*	Reindeer	72
8.	*Capreolus capreolus*	Roebuck	13
9.	*Felis spelæa*	Cave-Lion or Tiger	9
10.	*Hyæna spelæa*	Cave-Hyæna	57
11.	*Ursus spelæus*?	Cave-Bear	354
12.	—— *arctos*	Brown Bear	
13.	—— *priscus* s. *ferox*	Grisly Bear	
14.	*Canis vulpes*	Fox	15
15.	*Lepus cuniculus*	Hare	?
16.	*Lagomys spelæus*	Lemming	1

The order of distribution of the remains of these animals in the cave is fully described in Mr. BUSK's Report. From this it results that:—

Few bones, and no teeth or fragments of tusk, of the Elephant were found, and those few belong to the earliest occupancy of the cave: both the specimens occurring in the shingle bed were gnawed and probably brought in by some Carnivore.

The remains of the Rhinoceros were far more numerous, and increased in numbers in proportion to the distance from the entrance, and were probably taken into the deeper recesses of the cavern to be devoured by Hyænas or Tigers. They were mostly deep in the cave-earth in all parts of the cave.

---

* All the ursine remains from the Gower caves, that have come under Mr. BUSK's observation, appear to belong to the so-called *Ursus priscus* (s. *ferox fossilis*, BUSK).

† It is a question whether the *Arvicola*, *Sorex*, and some birds should not be included in the later part of the Cave period. See particulars of "finds" Nos. XIV., XLI., LIV., & XCIX.

The Horse was less abundant. Mr. Busk mentions several instances in which the limbs seem to have been brought into the cave while held together by their soft parts, and the bones afterwards dispersed, as in the case of an astragalus and tibia found 50 feet apart, two phalanges 36 feet apart, also two metacarpal bones belonging to the same limb 23 feet apart. Three specimens are from the fourth and the rest from the third bed.

The bones of the Ox were in about equal numbers with those of the Horse. One specimen was found in No. 4 bed and the others at variable depths in the cave-earth. We see no objection in connecting some of the specimens found in the Flint-knife Gallery with others found in the West Chamber, notwithstanding the difference of mineral characters.

Next to the Bear the remains of the Reindeer were most plentiful; and they occurred at all depths, from the surface of the stalagmite down to the top of the shingle bed, in the three chief passages. Mr. Busk's measurements show the animal to have been intermediate in size between the American and the Norwegian variety.

Few remains of the Red Deer were found, and of these six were basal portions of shed horns. They were mostly gnawed, and, except one found in the stalagmite, they were all in the cave-earth.

The Roebuck is equally scarce with the Red Deer, and several of the few dispersed specimens belonged apparently to the same animal. They were all in bed No. 3.

Of the Lion or Tiger most of the very few bones were deep in the cave-earth, chiefly in the Flint-knife Gallery, and several belonged to the same animal. The teeth were in large proportion.

In the case of the Hyæna the preponderance of teeth is again noticeable, and, like with the remains of the Lion, a large proportion of the specimens were deep in the cave-earth, and became rare near the surface. The West Chamber, Flint-knife and Reindeer Galleries were nearly equally resorted to by it: there is an entire absence of the bones of very young animals.

The number of the bones of the Bear exceeds that of all the other animals put together. A great part of them occurred at some depth in the cave-earth, but many were also found on its surface and in the stalagmite. Comparatively few specimens were gnawed; and generally the bones of the young animals, of which there were a large number, were neither gnawed nor rolled. They were mostly met with in the Reindeer and Flint-knife Galleries.

The remains of the Fox were scarce; some may be of recent origin, but a sufficient number show evidence of antiquity. One specimen was 8 feet deep in the cave-earth.

The same remark applies to the Hare, the remains of which, scattered in the two main galleries, were, however, much more numerous and superficial.

Only one specimen of the Lagomys was found, and that on the surface of the cave-earth far in the Reindeer Gallery.

These species represent the succession of animals frequenting the cave, or those living in the district, during the time the cave-beds were accumulating*; and the question next to be considered is the manner in which their bones were introduced. It is evident that the cave served for a very long period as a passage for water, though there appears equal reason to believe that the bones were not brought in by water; while, at the same time, we think that the cave could not be considered a Hyæna-den in the ordinary acceptation of the word.

In the first place, the shingle may have been brought in by a stream entering through the lower opening of the West Chamber, passing thence along the Flint-knife Gallery and the northern branch of the Reindeer Gallery. This stream, or its affluents, must have flowed over the slates, grits, and shales to the westward of Brixham, pebbles of which rocks, together with others of greenstone and ironstone, have been carried into the cave along with the more numerous local limestone pebbles. The area of drainage is, however, so small and the rocks so impermeable, that the stream would have been occasionally dry; and at such periods probably were the remains of the Mammoth, Horse, and Ox, which then inhabited the district, brought in at intervals by Tigers and Hyænas and devoured on the spot, for the bones show little traces of wear and much of gnawing.

In the second place, the bone-earth shows an entire change in the hydrographical conditions, while the palæontological conditions remain unaltered. Water charged with silt probably found its way into the cave by the lower or north entrance and deposited the cave-earth, in which occurs so great an accumulation of bones, including, in addition to the above-named animals, those of the various Deer, Bears, Fox, Rhinoceros, Hare, and Lemming. Looking at all the circumstances of the case, I consider it most probable that at that second period the cave was at times dry, and at other times flooded, not by streams flowing in from higher ground, but by flood-waters from streams at a level lower than that of the cave—that during the former intervals the cave continued to be frequented by Carnivores who brought in their prey to devour—and that with each successive inundation successive collections of bones were covered up and imbedded in the sediment with which the flood-waters were charged.

There are two facts frequently noticed by Mr. Busk and apparently irreconcilable, but which are in perfect accordance with this view of the subject. The one is that many of the bones, although found at some depth in the cave-earth No. 3, are yet slightly incrusted with stalagmite; and the other is that, as already mentioned, some of the bones show a condition which Mr. Busk considers to be the result of exposure to the sun and air on the surface of the ground. But if we follow out what may have been the consequence of the state of things we have suggested, both these effects would in all probability have resulted therefrom; for it is not conceivable but that, under favourable conditions, the water dripping from the roof of the cave must at all times have tended to the formation of stalagmite *; and, in fact, Mr. PENGELLY has shown that under such conditions (probably sheltered places) stalagmite did form alternately with the cave-earth. It would therefore follow that those bones which, from time to time, were exposed on the surface of the floor of the cave to the drip from the roof would receive an incrustation of carbonate of lime of thickness proportionate to the time between their being left by the predatory animals on the floor of the cave, and their being covered up by silt (the cave-earth) from some subsequent inundation. We know also that stalagmite did not form in all parts of the cave; and where such was the case, or where the bones were more out of the reach of the inundating waters, some of them must have been exposed to the long-continued action of currents of air in the cave, and such action probably produced the drying and weathering effects referred by Mr. BUSK to atmospheric action outside the cave. It was only when the cave was no longer subject to the recurrence of inundations that the formation of stalagmite became uninterrupted, and that the slowly accumulating layers of carbonate of lime formed the great stalagmitic mass, which finally sealed up the cave-earth with its contained multitude of bones.

---

* See Part 2 of Mr. Busk's report, which gives the relative mean depth at which the remains of the different animals were found.

As the deposit of the cave-earth proceeded, a change appears to have gone on in the animals frequenting the cave, either from lapse of time accompanied by a change in the animals frequenting the district, or else owing to the circumstance of the cave having become gradually drier and less subject to flooding. The remains of Elephant, Rhinoceros, and Cave-Lion gradually disappear, and those of the Hyæna become less common, whilst the Bears increase largely in numbers. Both circumstances combined, and possibly the presence of so powerful and savage an animal as the Grisly Bear, may have tended to the exclusion of the Hyænæ; but the same cause will not account for the great number of the common Brown Bear which frequented the cave during its later period. This animal seems to have made it a place of habitual resort, and to have taken possession of the more retired parts of the cave, such as the Flint-knife Gallery and the further part of the Reindeer Gallery, to the almost entire exclusion of other predatory animals. Instead of detached bones, numbers of bones of Bears, including those of very young cubs, were found together, leading to the inference that they were the remains of animals which died or were killed on the spot †; and as they are neither gnawed nor dispersed, it may be inferred that the Hyænæ had ultimately ceased to frequent the cave.

Contemporaneously with the latter change is the gradual appearance of the smaller mammals, rodents, and birds in the cave. A few of their bones have been found as deep as 4 feet in the cave-earth No. 3; but the greater number occurred on the surface of this bed and where it is not covered by stalagmite. From the recent-looking state of the bones of the Hare, though found at this depth, their antiquity might be questioned;

---

* The coating of some of the pebbles, the cementation of portions of the shingle bed, and the thick mixed deposit of ordinary stalagmite and crystalline calcareous spar in the Crystal Gorge, which was out of the main water-channel, points to the prevalence throughout the whole time of similar conditions.

† Sometimes possibly drowned by the inundations to which we have referred.

but it is to be observed that some of the bones of the larger mammals have also a very recent aspect.

With the appearance in the cave of the smaller common rodents now living in this country, we have to note a remarkable exception, that of the Lemming (*Lagomys spelæus*)*. At the same time it is also evident that a certain number of the older cave-animals, including the Reindeer, Ox, Horse, Roebuck, and Bear, and possibly the Mammoth, lived on to a comparatively late period in the history of the cave, as their remains were found in several instances in and upon the stalagmite floor, the deposition of which marks the period when the main entrances into the Brixham Cave were finally closed by falling débris to all except the smaller burrowing animals and a few bones introduced through fissures opening on the surface.

Although no line of demarcation in the fauna can be drawn from the accidental occurrence of the stalagmite floor, which seems due to favourable circumstances rather than confined to any particular period, still it is to be noted that the smaller and common animals do not appear till at a late period in the history of the cave, and when the deposition of the cave-earth had almost or entirely ceased. Did this arise from their more recent introduction into the district? to a change in the climatal condition and the dying out of the larger Mammalia? or was it (as we think more probable) merely a circumstance dependent chiefly upon the cave becoming drier, more closed up, and less resorted to by the larger animals?

Some doubt must always attach to the determination of the relative antiquity of the cave-remains, owing to the several possible causes of disturbance, whether by physical operations which rearranged the contents of the cave, or by the agency of animals or of man producing local displacements. It is well known that fragments and pebbles of an older stalagmite floor are sometimes found in the beds below the existing compact stalagmite now forming the floor, and also that portions of an old stalagmite floor are sometimes found attached to the sides of the cave in a higher position than the existing bed of stalagmite. SCHMERLING, in his account of the caves of the neighbourhood of Liége, describes several instances of the former, and the latter your Reporter has noticed in the celebrated "Grotte D'Arcy," near Auxerre. In this case the under surface of the stalagmite was coated with pebbles. Mr. PENGELLY records precisely similar facts as part of the phenomena of the Brixham Cave. Now it is evident that this could not have taken place without a large remodelling of the contents of the caves. In the first place, the caves were filled to a much greater height than at present with shingle, and this shingle was directly covered by a bed of stalagmite. To have broken up this bed, to have removed part, or lowered the whole mass, of shingle, and to have worn the broken fragments of the stalagmite into pebbles, indicates a considerable disturbance, such as, if any organic remains existed in that portion of the bed which was so disturbed, would have removed them from their original position, and subjected them to more or less wear and fracture. But as some of the fragments of stalagmite are rolled and some nearly angular, the test of wear or of angularity in distinguishing the older remains from those of more recent introduction becomes of no avail, as the disturbing cause has not produced a uniform result on materials, all of which must have been originally of the same character.

---

* This circumstance tends to give a greater antiquity to a portion of the smaller remains than from their condition and position we might have been disposed to assign to them.

The treading of the ground by the larger animals, the habit of hiding their spoil, or their search after spoil, and even the agency of man, whose presence here we shall presently show, may also have led to some displacement of the bones in a cave where they were lying loose on the floor or only buried a slight depth in soft cave-earth. Thus, while on the one hand we see cause to believe that some of the bones may not be in their original position, yet on the other hand, in case of the bones occurring together, it does not follow (owing to causes we have before referred to) that because they differ in mineral character they are necessarily of a different age. It is evident that as other conditions besides those of age and imbedding, such as previous weathering or stalagmitic coating, influence the fossilization of the bones, it must be difficult to decide upon the limits of error to which such differences of condition may give rise. Though the fact of the variations in the state of the bones may be ascribed to several causes and does not vitiate the argument of antiquity, still it may be better to eliminate all such doubtful cases (and after all it is the general condition and aspect of the bulk of the remains upon which we must in the main depend), although the exceptions, even admitted, will be found to be so few as hardly to affect the main question at issue, whether as regards the actual or the relative age of the mammalian remains generally.

This group of cave-animals may be referred to a late quaternary period, probably coeval with and prolonged beyond that of the raised beach which in places fringes the south coasts of England; for mammalian remains of the same species have been found in the rubble beds which overly the raised beaches of Plymouth, Brighton, and elsewhere.

We now have to consider another question sought to be settled by the exploration of this cave; and although the antiquity of man has since been established on other grounds, this work must be ever considered as inaugurating, and as forming the first systematic attempt to solve, this important problem.

Traces of Man's work.—Amongst the extraneous materials found in the Cave were thirty-six specimens of chalk flint (see Mr. Pengelly's Table No. IV. p. 494)[*], fifteen of which show unmistakable evidence of having been artificially worked, and are of forms which have their modern analogues in the stone knives, skin-scrapers, and pointed flakes used by uncivilized man, while one specimen (6, 8) is of that extinct large spear-head type so common in the high-level gravels of Amiens and other places. Fourteen of these specimens are described by Mr. Evans (see p. 549). There are nine others of which the workmanship is very rude or doubtful[†], while there are seven which I think show no traces of having been worked at all. In the long interval since their discovery four specimens have been mislaid. The others may be sorted approximately as under:—

---

[*] In Mr. Evans's 'Ancient Stone Implements' the numbers in column X. of Table IV. are used. In this Report the numbers in the first column are given.

[†] These are marked by an asterisk; they are all from the shingle bed, except Nos. 14 and 18.

Worked FLINTS (*implements and chips*).	Nos. 1, 4, 5, 6, 7, 8, 9, 10*, 11, 12, 13, 17, 21*, 23*, 24*, 25*, 27*, 28, 29, 30, 31*, 32*, 33, 35* .	24 specimens.
FLINTS not worked† (*natural forms*).	Nos. 14‡, 18, 19, 20, 22, 26, 34 .	7 "
		31 "

Nos. 2, 15, 16, and 36 are mislaid; but, on the other hand, there are three extra specimens, one of which is worked and two are doubtful, upon whose numbers we cannot agree.

Omitting the nine more doubtful specimens and mere chips, the distribution in the Cave of the worked forms of flints, such as may have been used by man, was as under:—

	Reindeer Gallery.	Flint-knife Gallery.	West Chamber.	Pen and Keeping Galleries.	Total.	
CAVE-EARTH	5	3	1	2	11	15
SHINGLE BED	2	0	2	0	4	

While of the unworked flints the distribution is as follows:—

	Reindeer Gallery.	Flint-knife Gallery.	West Chamber.	Pen and Keeping Galleries.	Total.	
CAVE-EARTH	1	0	1	0	2	7
SHINGLE BED	1	2	2	0	5	

The four flint implements found in the bed of shingle were at depths of from 6 inches to 10½ feet, or, including the overlying beds, of from 8 to 14 feet. As the bed of shingle is, on the whole, perfectly distinct from the succeeding cave-earth, there can be no doubt that the associated flint implements, unless subsequently introduced by some artificial means, date also anterior to the cave-earth; and there is no appearance of the overlying ground, at the several places where they were found, having been disturbed either by man or by animals. In a few places mentioned by Mr. PENGELLY the shingle, it is true, is partly mixed with cave-earth; but there it seems to have been caused by the rapid influx or efflux of the flood-waters charged with the silt which formed the cave-earth, or to be owing to remnants of pebbles which remained lodged on the sides or roof when the shingle bed stood higher. They are evidently foreign to the bed, as the local fragments of limestone so common in it are all angular and show no indications of the action of a running stream to which the pebbles are due.

The relative position of the bones of the Cave-animals and of two of these Flint Implements is shown in the following Table, based on Mr. PENGELLY's Table IV. and Mr. BUSK's lists:—

---

† Specimen No. 3 is merely a fragment of slate nearly covered on one side with stalagmite.

‡ A specimen, No. 144 in the collection, corresponds in the description of its find in the "Register" with No. 14 of Table IV.

Number attached to the find in first column of Table IV.	Depth of specimen in the shingle bed.	Thickness of the overlying cave-earth.	Gallery in which found, and distance from entrance.	Animals remains of which were found in the cave-earth at the same distance from the entrance.	Number of bones of each species.
29.	8 feet.	13 feet.	West Chamber—5 feet (see "finds" Nos. 72, 73, 74, 75).	Elephant	4
				Rhinoceros	7
				Horse	2
				Ox	1
				Red Deer	1
				Reindeer	4
				Tiger or Lion	1
				Hyæna	13
				Bear	13
33.	10 feet.	4 feet.	Reindeer Gallery—34 feet (see "finds" Nos. 80, 105).	Horse	1
				Roebuck	1
				Reindeer	2
				Rhinoceros	3
				Hyæna	1
				Bear	1
				Elephant	1

In the West Chamber eight bones were found in the cave-earth at the same distance from the entrance as Flint No. 11; while in the Reindeer Gallery, over and within 1 foot on either side, twenty-one bones of various animals were found in the cave-earth overlying Flint No. 30. Both these flints were in the shingle bed.

The following specimens were, on the contrary, found in the cave-earth, and were associated with, or were beneath, bones of the different animals here mentioned*:—

No. of find in Table IV.	Animals whose remains were found on the same vertical with the bones, and the number of the latter (see Tables I. and IV.).	Depth in the cave-earth.				Distance from entrance.
		Flint.		Bones.		
		ft.	in.	ft.	in.	feet.
1.	Reindeer (1) (in the overlying stalagmite)	0	9	0	0	74
4.	Hyæna, Bear? (3)	2	0	0	9	37
6.	Rhinoceros, Reindeer, Bear, Horse, Hyæna (9)	3	0	2	0	31
7.	Roebuck?, Reindeer, Hyæna, Horse, Rhinoceros (6)	3	6	1	0	16
8.	Rhinoceros, Hyæna (2)	3	6	1	6	22
12.	Red Deer, Ox? (3)	2	9	0	9	15
13.	Horse, Hyæna, Rhinoceros, Reindeer (4)	4	0	3	6	26
17.	Deer, Hyæna? (2)	9	0	9	0	15

At the same distance from the entrance and the same depth in the cave-earth in the West Chamber as Flint No. 9 there were found fifteen bones of Bear, Hyæna, Ox, and Rhinoceros; while in the Flint-knife Gallery flint No. 5 was found overlying three bones of Ox and Bear.

Besides these cases—which determine, first, the occurrence of worked flints in the bottom or shingle bed, and the superposition on it at the same spot of a considerable thickness of undisturbed cave-earth rich in mammalian remains, and, secondly, the association of bones and worked flints at the same places in the cave-earth—it is well to remember that the relation of the cave-earth to the shingle is constant and uniform, and, further, that the cave-earth itself is overlaid throughout a great part of the cave (including those parts where the flint implements Nos. 4, 8, 12, 13, and 30 were found) by a layer of stalagmite in which bones of Bear, Reindeer, and Elephant or Rhinoceros were, in several places, found imbedded.

---

* The Register does not record the distance from the walls of the cave, so the superposition may not always be quite vertical; but from the small width of the galleries there is little room for error.

The Cave furnishes also some other slight indications of man's presence. Dr. FALCONER alludes to part of a Reindeer's horn (No. 4 find) which has an apparently artificial incision*; and Mr. EVANS also draws attention to the discovery of a small "cylindrical pin or rod of ivory," but the position of this is not certain. Two nearly round pebbles were also found in the shingle bed—one of siliceous sandstone, weighing 1 lb. 3 oz., in the West Chamber, and the other of red sandstone, weighing $5\frac{3}{4}$ oz., at the entrance of the Steep Slide Hole. The first is one of those hard pebbles forming the Budleigh-Salterton conglomerates,—beds which do not range westward of the Ex. This pebble shows, on the side opposite to that by which it is most readily grasped by the hand, the distinct marks and indentations arising from use as a hammer-stone. On the smaller and softer pebble these are less marked. These specimens are unique, and the first is of especial interest, as it seems to have been brought from a distance and could not have been introduced by natural causes into the cave†.

Amongst the débris of bed No. 3, Dr. PERCY noticed some pebbles of brown hematite, a mineral which does not occur on Windmill Hill. Mr. PENGELLY refers them to Furzeham Hill; at the same time they may have been derived from denuded portions of Parkham Hill, at the base of which this mineral is still found, and which is on the line of the valley above the cave; otherwise they must have been introduced by artificial means.

But although the evidence, taken altogether, sufficiently indicates the existence of man at the cave period, we doubt whether Brixham Cave was at any time inhabited by man. Caves have constantly been places of resort for uncivilized man, either for shelter or for security. When resorted to for these objects, traces of his habitation, in the form of refuse (whether of bones cast away at meals, of broken and lost tools of daily use, and, after the discovery of fire, of hearths and their surroundings), necessarily occur in quantities more or less abundant, according to the length of man's habitation. Further, when a common and brittle material is in use for implements, the number lost or spoilt must always have been large, as in the case of the caves of Les Eyzies, Moustiers, and others in the south of France, where rudely worked flints occur literally in thousands. Again, man usually takes possession of a cave when dry and capable of affording permanent shelter, so that the layers of débris formed during his period of occupancy are on a given zone,—that zone being generally above the deposit of cave-earth covering up the remains of animals which may previously have frequented the cave.

---

* Mr. BUSK sees reason to question this conclusion, see page 537.

† Budleigh Salterton is about twenty-five miles eastward from Brixham. Mr. PENGELLY informs me, however, that quartzite pebbles are occasionally met with on the Devon beaches. A broken quartzite pebble has also been found in Kent's Cavern (see Brit. Assoc. Report, 1870, p. 22).

In the instance, however, of the Brixham Cave, although we have in evidence these primitive works of man, they are so few and so scattered, and they occur also on levels so widely different (no two, in fact, of the fifteen flint implements found there having been met with on the same level), that it is not possible to conceive that man inhabited the cave at any time. The specimens are not numerous enough: they are found isolated and without any corroborative adjuncts.

Nor do we think that the flints could have been brought in by wild beasts with human prey, for not a fragment of a human bone was found in the cave; whereas, like with the animals serving as prey, some of the remains of man in the shape of gnawed bones or teeth must, in that case, have escaped destruction. Could the worked flints have been washed in, as the unworked flints doubtlessly were, with the shingle of the fourth bed or with the silt of the third bed? This is possible; still we are not disposed to adopt that view, inasmuch as although some of the specimens show marks of wear, that wear arises rather from use, and none exhibit the general wear and rounding produced by running water; the wear is, in fact, often so slight, that in the instance of the remarkable flint implement which was found broken in two pieces (p. 550), and each piece in a different gallery, the broken edges (*ff*) when brought together fitted as closely as two pieces of freshly broken porcelain. One fragment (No. 6) was found in the Flint-knife Gallery on the line of main water passage and the other (No. 8) in a different direction in the Pen Gallery, so that their position was in all probability determined by artificial agency. The worked flints also in the cave-earth are to those in the shingle in the proportion of nearly 3 to 1; whereas with the unworked flints, on the contrary, the proportions are more than reversed, there being only 2 in the cave-earth to 5 in the shingle bed, where the stream was the natural means of their introduction. The flints in the cave-earth in No. 3 bed are in the inverse ratio in which as extraneous bodies they should occur had natural agencies only been in operation.

After full consideration of the subject, we can only conclude that the worked flints were lost or left behind by man during occasional visits to the cave, either for the sake of temporary refuge or in following prey which may have sought shelter there. The former alternative is the more likely, as during the formation of the shingle, in which the four specimens were found, the cave was but little frequented by animals, only 7 bones occurring in that bed; whilst in the cave-earth, though 751 bones were found, not more than eleven worked flints were met with. The proportion of bones to flints shows therefore no relation one to the other, whether it be considered that man was subject to be the occasional prey of carnivorous animals, or whether man sought his prey amongst the herds of wild deer, oxen, and some other animals. On the other hand, the absence of human bones would seem to indicate that early man had the skill and activity necessary to avoid falling a prey to the powerful wild animals of the period, while at the same time his senses, like those of animals, must have been as acute and keen as theirs to have carried him safely through the deep and narrow recesses of such a cave as that of Brixham; for it is to be noted that although the larger proportion of flint implements were found near the entrances where a glimmer of light might penetrate*, still a few were found 30 and 50 feet (and in one case as many as 74 feet) from the nearest external entrance, where little if any light could penetrate; and there is no evidence of early man having been acquainted with the use of fire.

The view we have suggested with respect to the early condition of Brixham Cave is one also in unison with the other phenomena of the cave, which, from the evidence we have now gone through, points, we conceive, to the following conclusions. In the first instance, some small watercourses, draining a small upland tract of Devonian slates and shales situated between the site of the cave and the valley of the Dart, emptied themselves and were lost, as is common now in limestone districts, in the narrow fissures or open joints of the limestone rocks. These were the channels along which were transported the worn and rolled shingle derived from those rocks and which were deposited along the bottom of the cave, forming bed No. 4. As the fissures in the limestone could but have been on the level at which these streams flowed, the valley of Brixham and its tributaries, which then as now formed the channels of drainage of the district, must have been from 70 to 80 feet less deep than at present.

It would seem that the stream originally entered the cave by the West Chamber† and escaped through the north entrance, and perhaps in part through the Steep Slide Hole—the sea-level being then probably the one marked by the old raised beach, which would show that the land then stood about 30 feet lower than at present. After filling the lower part of the fissures with shingle, the prolonged action of the stream wore and expanded the upper part of them into the wider passages at present constituting the cave, and finally nearly filled them with shingle. The lower wall-grooves (*b b*) may have formed before the shingle had choked up the cave, when, in fact, the stream was in full force, and the upper one (*a a*) at a later period, when the current was more impeded, and when, judging from the level of the old stalagmite floor, the shingle had found an exit through the north entrance. The traces of a reverse or inward dip of the wall-grooves between the road entrance and the Steep Slide Hole may be due to the influx of the flood-waters at a later period. During this period, when the streams were low or dry, the cave was resorted to, on a few rare occasions, by animals to devour their prey; but at this time they cannot be traced far beyond the entrance—in no case more than 36 feet in the Reindeer Gallery, and, in the Flint-knife Gallery, to 25 feet from the west entrance. In the same way we recognize the restricted presence of man, in the two flint implements found at a distance of 34 feet from the north entrance, and the two within 7 feet of the west entrance.

After the cave had become choked with shingle, the stream, either from that cause or from the deepening of the channels outside, kept more in the main valley, and a period of quiet succeeded, during which a first bed of stalagmite was deposited immediately upon the bed of shingle. Remnants of this old layer of stalagmite, with the pebbles forming the top of the original shingle bed attached to its under surface, were found adhering to the sides of the cave, 3 to 4 feet above the second or later stalagmite floor. The breaking up of this layer of stalagmite and the lowering of the surface of the shingle bed to the extent of from 6 to 10 feet, was accompanied by a complete change in the state of the cave (see figs. C, D, E, Plate XLII.).

---

* The first 16 feet was then, however, an open fissure.

† The openings in the South Chamber may also have given passage to a stream.

These effects may have been produced either by an irruption of water carrying away part of the shingle, and so undermining the stalagmite, or by the breaking up of the stalagmite, and the settling down of the shingle deeper into the fissures, by earthquake movements. We are disposed to adopt the latter alternative; for Mr. PENGELLY has remarked that the surface of the shifted shingle, instead of presenting a depression in the middle with edges rising up to the sides of the passages, is, on the contrary, raised in the middle and is depressed on the sides—a form which is hardly compatible with the action of flowing water, but rather accords possibly, in our opinion, with the results of the vibrations and settlements caused by earthquake action. From this moment new conditions of the cave commenced. Instead of fissures receiving shingle-bearing streams, and water more or less constantly flowing through the cave, we now come to a period when the cave was habitually dry, though it remained subject to occasional floods from the main stream of the Brixham valley, then in the course of excavation. The flood-waters charged with silt deposited the cave-earth gradually during each successive inundation, like as, in other districts, the loess was deposited during the river-floods in the more sheltered spots of the main and lateral valleys; while during the whole time blocks and fragments of the old high-level stalagmitic floor continued to fall in more or less abundance.

We admit the difficulties of the case,—of realizing how, in so short a course as the Brixham stream had, and with so small an area of drainage, a sufficiently powerful body of water could be collected to excavate such a valley; but it is a difficulty which meets us in many valleys of denudation when we contemplate the small causes at present in operation with the comparatively gigantic effects produced. We can only account for it, as we have done elsewhere, on the hypothesis of an intensely cold climate, of which we have such abundant evidence, accompanied by a greater rainfall, by spring floods of great power such as now occur annually in all arctic regions, and by ice action. It is further possible that a slow movement of elevation was in progress during this period, which counteracted the loss of gradient in the lower part of the valley caused by the process of denudation. The submarine forest of Torbay, which afterwards grew on land now 30 feet beneath the sea, shows the entire rise at one time to have been 40 feet or more above the present sea-level, or 70 feet or more above the level of the old raised beaches, to which extent the fall of the stream was then increased.

The breaking up of the first and original bed of stalagmite, and the lowering of the surface of the bed of shingle, whatever may have been the cause, gave greatly increased room in the cave; and as it was no longer a mere channel for a flowing stream, but, on the contrary, presented for certain periods open passages with a dry bed of loam and limestone débris, it became a place of resort for the predatory animals of the district. They there brought their prey to devour, scattering the gnawed bones of the disjointed limbs in different and distant parts of the cave. The Hyænæ carried their prey to all the main passages of the cave, but sought chiefly for that purpose the more retired galleries, while their own remains are more equally scattered. Of the 669 bones determined by Mr. BUSK, if we omit the bones of the Bears, we find that the distribution of the others was as follows:—

	West Chamber.	Flint-knife Gallery.	Reindeer Gallery, North.
Bones of the various animals excepting Bears	57	124	109
Bones of Hyæna..............................	21	18	18

It may, however, be doubted whether the Hyænæ made the cave more than a place of temporary resort, as, unlike in other old caves which they frequented, no coprolites of Hyænæ have been found here, though that may admit of the explanation before given. But although now generally dry, the cave continued subject to be flooded, perhaps at long intervals; and it is probable that the water found its way into the cave by the north entrance and so through the Reindeer Gallery, the Flint-knife Gallery, to the West and South Chambers. As it retired we may suppose it to have caused, by its fall over the limestone ledge above *d* (fig. 2, Plate XLIII.) in the West Chamber during rapid subsidence, the disturbed and abnormal position of the bones in the cave-earth there noticed. To such advance and retreat of the waters may also be attributed the irregular deposition of the cave-earth, the variable depth at which bones of the same limbs are buried, and the silting up of the passages furthest from the point of entrance of the waters, which latter their outflow kept clear. The influx and efflux of water was also of sufficient power to move and rearrange the bones throughout its course, as, according to Mr. PENGELLY, they were mostly found, not as scattered indiscriminately by wild animals, but lying with their length in the direction of the passages of the cave. By the repetition at distant intervals of these inundations, and by the accumulation during these intervals of fresh crops of bones, the bone-bearing cave-earth was gradually formed; at the same time the occasional visits of man are indicated by the rare occurrence of a flint implement lost as he groped his way through the dark passages of the cave—into the more innermost recesses of which he now occasionally penetrated, though keeping, in most cases, to within 20 to 50 feet of one of the main entrances.

As the denudation and deepening of Brixham valley proceeded, the cave became less and less subject to inundations, that after a time ceased to reach the level on which it stood. With this greater freedom from inundations, the increasing number and proportion of their bones show that the cave became a place of more frequent habitation for Bears. Their remains in all stages of growth, including those even of sucking cubs, were met with in greater numbers than were the bones of any other animal. These animals resorted especially to the darker and more secluded Flint-knife Gallery, where 209 out of 354 of their determinable bones were found, whereas only twenty-six were met with in the West Chamber and 116 in the Reindeer Gallery.

Finally, whether from a change of climatal conditions or from the cave becoming quite out of the reach of the flood-waters, and partly possibly from its being more blocked up, the formation of the stalagmite floor proceeded without interruption. The cave, however, still continued to be the occasional resort of beasts of prey, for remains of the Reindeer, including a fine entire antler, together with bones of the Bear, the Rhinoceros, or the Mammoth, were found in the stalagmite floor. But no flint implements and no remains of man are found in this position; and while therefore we have reason to believe that the cave continued to be frequented by some of the older Mammalia as long as it remained open, we have no evidence that it was latterly resorted to by man. After a time the falling in of the roof at places from the effects of rain and weathering (and every earthquake movement must also have detached blocks from it) stopped up some parts of the cave, and closed its entrances with an accumulation of débris. From that time it ceased to be accessible, except to the smaller rodents and burrowing animals, and remained unused and untrodden until its discovery in February 1858.

The instances in which the remains of man or of his works have been found in caves in association with the remains of extinct Mammalia are many. They were duly noticed by SCHMERLING in Belgium, by TOURNAL and others in the South of France, by Dr. BUCKLAND in Wales, and by Mr. M^cENERY and the Natural-History Society of Torquay in Kent's Hole; but in all these cases they were either explained away, in many instances by the observers themselves, from a preconceived improbability or rather impossibility of the circumstance, or the facts were refused credence on the same grounds and the evidence negatived, as in the case of Kent's Hole, without investigation. At this time it is not necessary to contend for the correctness of many of those observations; they are too numerous and too well attested to admit of doubt, and are now generally accepted; at the same time it is to be observed that the discovery and early reports of Brixham Cave had a very important influence in bringing about such a result. The discoveries of SCHMERLING and others had dropped into oblivion, the assertions of M. BOUCHER DE PERTHES were ignored, until the certainty of the facts established by the exploration of Brixham Cave showed the strong *primâ facie* evidence of the contemporaneity of man and of the great extinct Mammalia. Fresh from this new ground, and strong with convictions acquired on other grounds, Dr. FALCONER visited the valley of the Somme in which the reputed works of man had, it was said, been found in quaternary deposits; and so satisfied was he with the force of the evidence, taken in conjunction with the observations already made at Brixham Cave, that he at once urged in the strongest manner inquiries into its correctness and value, which we ourselves had long been contemplating, but which might have been still longer postponed but for the corroborative testimony afforded by Brixham Cave. Late as we are therefore in bringing forward the whole of the evidence afforded by this cave, it must not be overlooked that, however interesting the full record may prove, the exploration has already had an immediate and direct value in the successful impulse which it gave to so important a question as that of the antiquity of man. Well established as this fact now is from other and independent grounds, nevertheless the evidence of Brixham has its own special points of value,—in the completeness of its record, in the certainty of its data, and in the fact of its having been the first entire ossiferous cavern which was worked out in a systematic and complete manner, and the contents preserved for scientific use and reference*. It records also a time in geological science of very great importance, one marked by the removal of the boundary which had hitherto divided man from the extinct animals—a barrier no sooner removed than the search, before directed timidly to the measurement of man's age by the span of historical and traditional periods, became now boldly directed back into the later geological periods in search of his first appearance. But, notwithstanding the range of our new vista, we should not so much speculate on its indefinite extension, but rather seek to obtain those indisputable data, whether as regards the true position of the strata in which such remains may be found, or as regards the artificial character of those remains, without which we might have continued yet to hesitate to admit man's existence in the Quaternary period.

JOSEPH PRESTWICH.

Agreed and approved. { GEORGE BUSK.
R. GODWIN-AUSTEN.
A. RAMSAY.

DESCRIPTION OF THE PLATES.

PLATE XLI.

Fig. 1. Photograph of Entrance to Cave after clearing away the talus of limestone débris by which it was hidden. "*f*," north and south joint coincident with the line of the Reindeer Gallery.

Fig. 2. Section of Brixham Valley, showing the position of the Cave on the slope of Windmill Hill. The 150-feet terrace is on the authority of a section by Mr. PENGELLY.

Fig. 3. Geological Sketch Map, showing the direction of Brixham Valley and the rocks through which it passes.

---

* All the specimens are to be deposited in the British Museum, and the original documents and maps in the archives of the Royal Society.]

PLATE XLII.

Plan of the Cave, with the position of the several sections given in Plate XLIII. The original names are retained, with the exception of that given to the north entrance and certain letters indicating the Galleries.

PLATE XLIII.

Fig. 1. Section along the Reindeer Gallery from the entrance to the Flint-knife Gallery. The original surface line continued sloping to the road. The entrance is here represented after the brickwork had been introduced into the first part of the fissure *f* and the finishing of the doorway. s', remaining portions of old stalagmite, is from Mr. Pengelly's section.

Fig. 2. Section along the Flint-knife Gallery from the Reindeer Gallery to and across the West Chamber. The entrance to a short side gallery is shown under *m* and to Munday's Gallery at and above *d*.

Figs. A to G, M M and N N. Sections across different galleries. In the section M M the entrance to the Flint-knife Gallery is traced in central outline, and in the section N N the entrance to Kelly's Gallery. The position of the old stalagmite in fig. 1 and the rounded surface of the shingle bed No. 4, in the several cross sections, is given on the authority of Mr. Pengelly's sections.

The plan and sections were taken by Mr. Bristow, *of the Geological Survey, with the exception of the lower part of Bed No.* 4 *and of the line defining the bottom of the cave after that bed was removed. These additions were made by* Mr. Bovey *of Torquay.*

PLATE XLIV.

N.B. The figures, with the exception of fig. 13, Plate XLVI., are all of the natural size.

Fig. 1. Portion of the middle of the shaft of the femur of *Rhinoceros* gnawed by Hyæna.

Figs. 2, 3. Upper and lower aspects of the astragalus of *Rhinoceros tichorhinus.*

Fig. 4. Outer aspect of the third upper deciduous molar, left side, of *Rhinoceros tichorhinus.*

Fig. 5. Crown surface, in which there is no appearance of the median pit or "accessory valley" being formed by the fusion of two "combing" plates.

Figs. 6, 7. Similar views of the second upper deciduous molar of the right side, in which the same thing is still more plainly shown.

Figs. 8, 9. Similar views of a less worn third upper deciduous molar of the right side, on which no cementum appears to have been deposited. The outer or dorsal lamina of enamel is entirely removed. This specimen still more strikingly shows the median pit surrounded by a continuous wall of enamel, and that the inner lamina of the dorsal enamel plate is continued uninterruptedly from one side of the tooth to the other.

Figs. 10, 11. Outer aspect and crown surface of the first lower premolar, left side ($\overline{\text{pm } 2}$).

PLATE XLV.

Fig. 1. Portion of the left mandible of *Hyæna spelæa*, with the canine and three molars.
Fig. 2. The radius.
  - *a.* The proximal articular surface.
  - *b.* The distal articular surface.

Fig. 3. The tibia.
  - *a.* The proximal articular surface.
  - *b.* The distal articular surface.

Fig. 4. A portion of the maxilla of *Felis spelæa*, containing the second premolar.
Fig. 5. A canine tooth of *Felis spelæa*.
Fig. 6. A carnassial tooth of the same.
Figs. 7, 8. The fifth and fourth proximal phalanges of the manus.

PLATE XLVI.

Figs. 1, 2, 3, 4. Various canine teeth of *Ursus*.
  1. *U. spelæus*?
  2. *U. priscus.*
  3. *U. arctos.*
  4. *U. arctos*?

Figs. 5, 6. Two last lower molars.
  5. *U. arctos*?
  6. *U. priscus.*

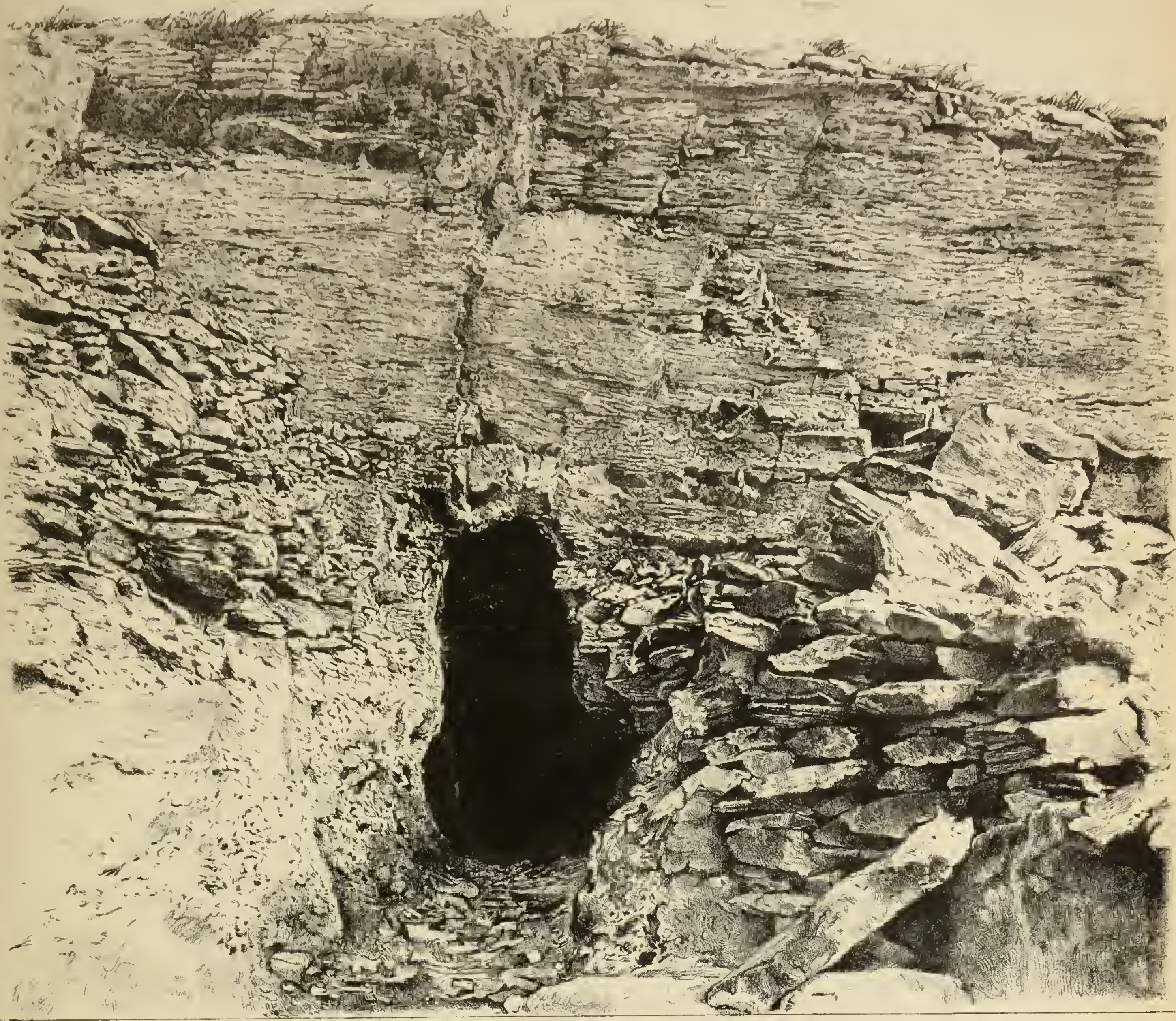
Fig. 7. Astragalus of *U. priscus* or *spelæus.*
Fig. 8. Astragalus of *U. arctos*?
Fig. 9. Os unciforme, *U. priscus*?
Fig. 10. Os unciforme, *U. arctos*?
Fig. 11. Portion of maxilla with four teeth of *Bos primigenius.*
Fig. 12. Dentition of *Lagomys spelæus.*
Fig. 13. Ditto, × 2 diameters.
Fig. 14. Peculiarly formed $\underline{\text{pm } 4}$ of *Ursus* ——?

PLATE XLVII.

Odontograms, or graphic representations of the dimensions of the teeth in:—

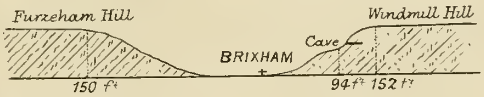
1, 6, 11. *Ursus spelæus.*
2, 7, 12. Mean of all fossil species of *Ursus*, taken together.
3, 8. *Ursus ferox fossilis* (mihi).
13. *Ursus priscus*, Cuv. (*fossilis*, Gldf.). (Brit. Mus. sp.)
4, 9, 14. *Ursus ferox* (recens).
5, 10, 15. The Brixham-Cave Bears.
16, 17, 18. *Ursus arctos.*
19, 20. *Ursus maritimus.*

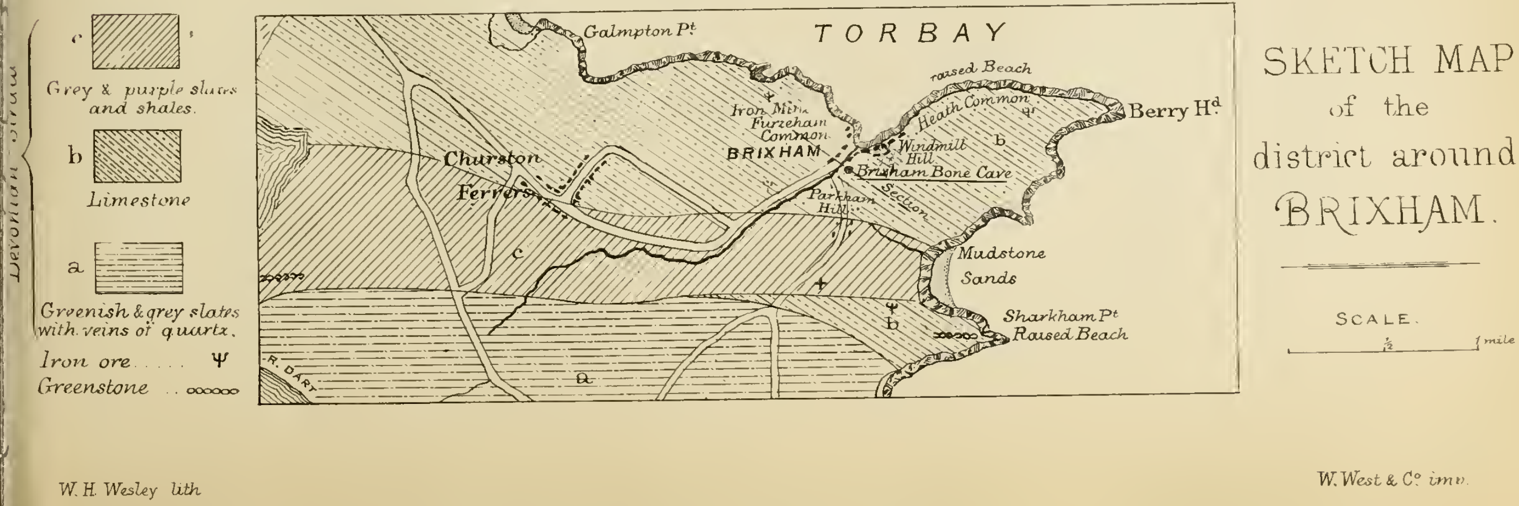
Fig. 1. Road Entrance to Cave after removal of talus.



From a photograph

Fig. 2. SECTION ACROSS THE VALLEY AT BRIXHAM.





SKETCH MAP
of the
district around
BRIXHAM.

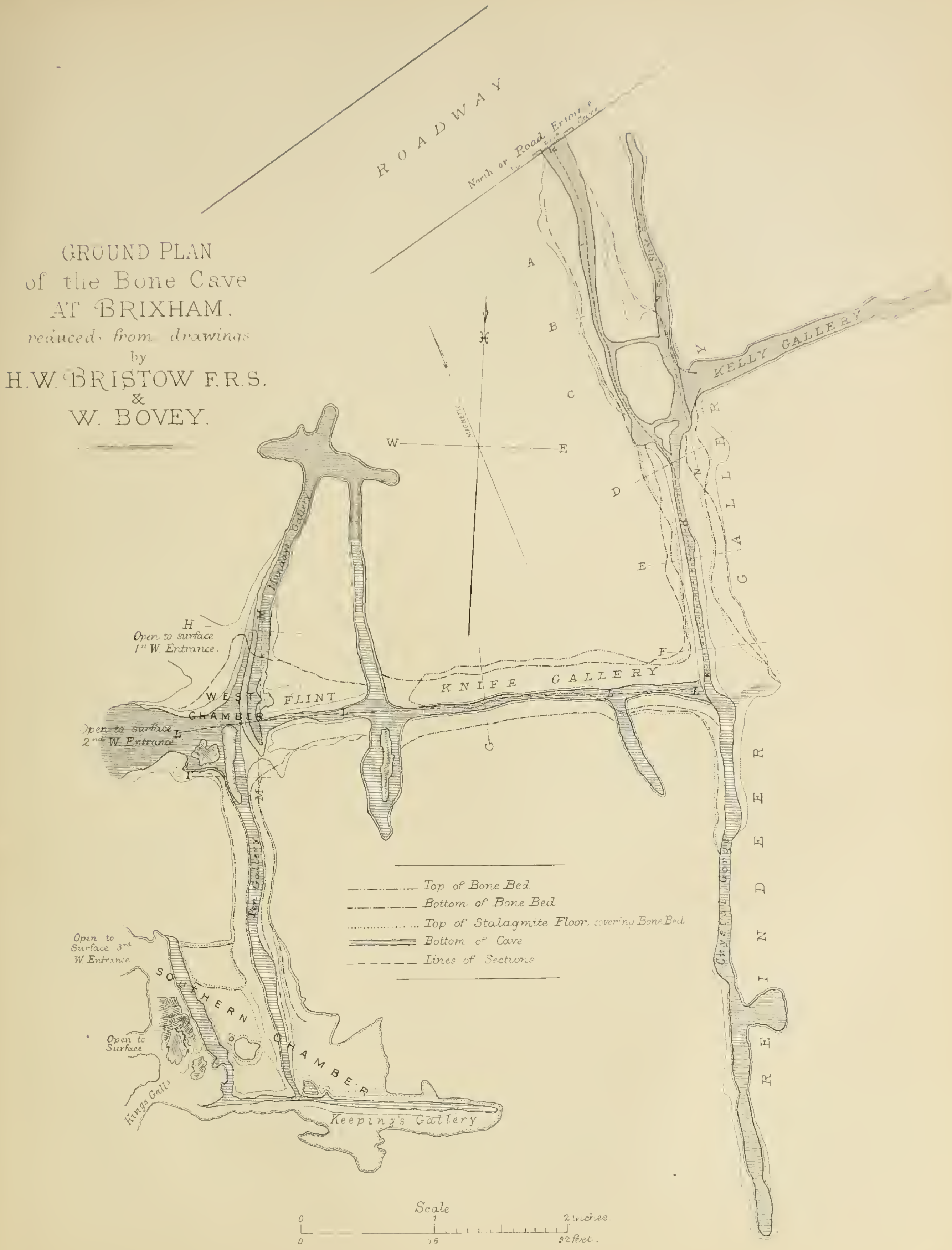
W. H. Wesley lith.

W. West & Co. imp.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

GROUND PLAN
# of the Bone Cave
AT BRIXHAM.

reduced from drawings
by
H. W. BRISTOW F.R.S.
&
W. BOVEY.



W.H. Wesley lith. [illegible] & C° imp.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

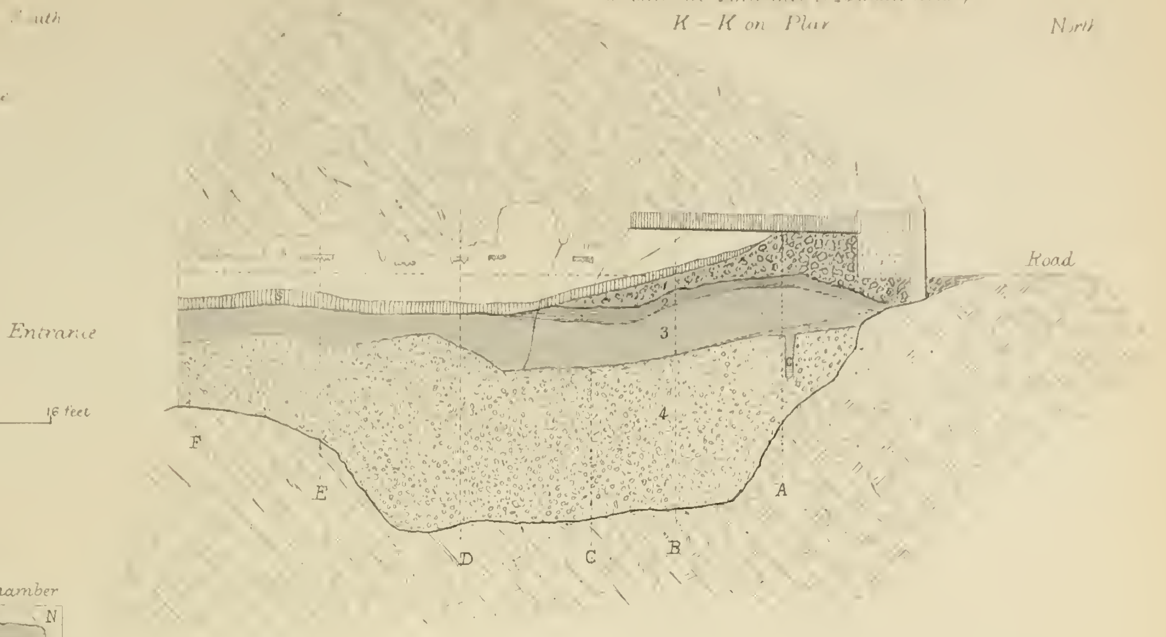
Fig. 1

Longitudinal Section of West side of Cave at Entrance of Reindeer Gallery

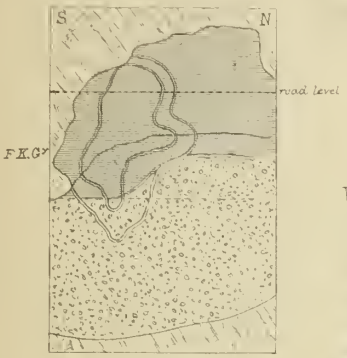
K — K on Plan

S' Old Stalagmite
s Stalagmite
1 Breccia
2. Black bed
3. Cave earth
4 Shingle
.........Level at Road Entrance

Scale

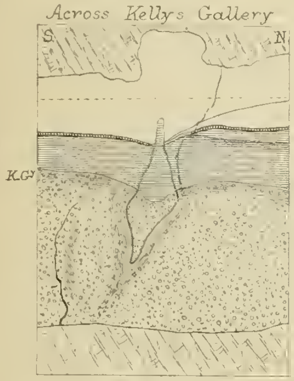


Across West Chamber



M — M

Across Kelly's Gallery

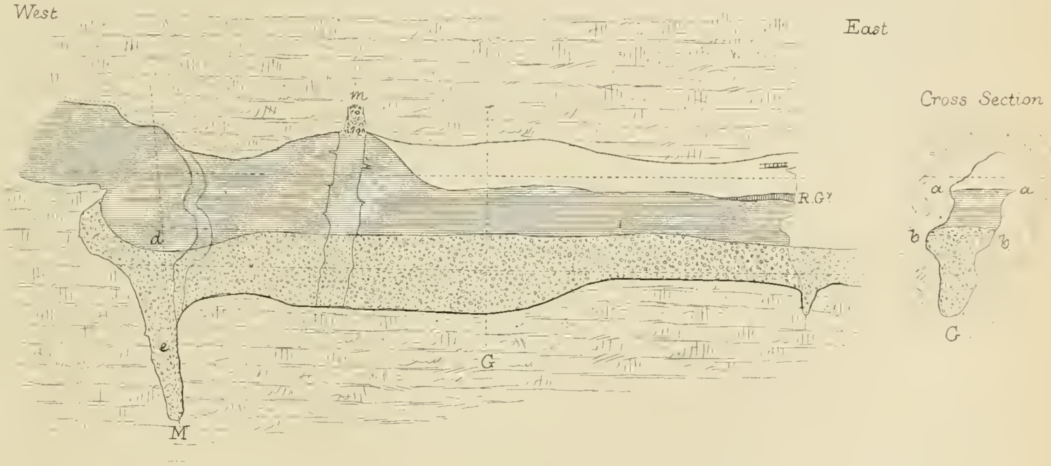


N — N

Fig. 2.

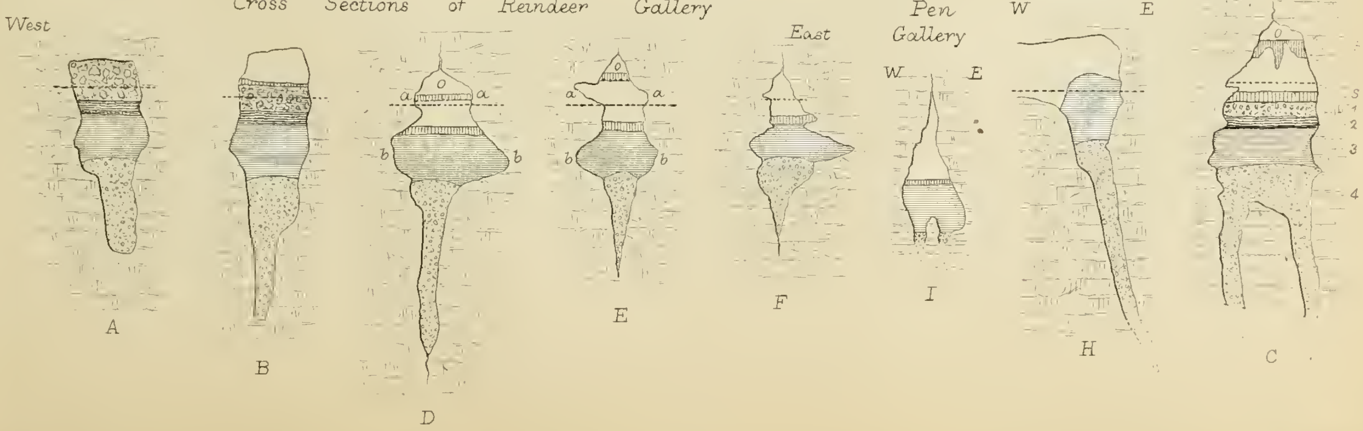
Longitudinal Section of North side of Flint-Knife Gallery, into West Chamber

L — L on Plan



Figs 3

Cross Sections of Reindeer Gallery



W.H. Wesley lith.

W. West & Co. imp.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

Fig. 2.

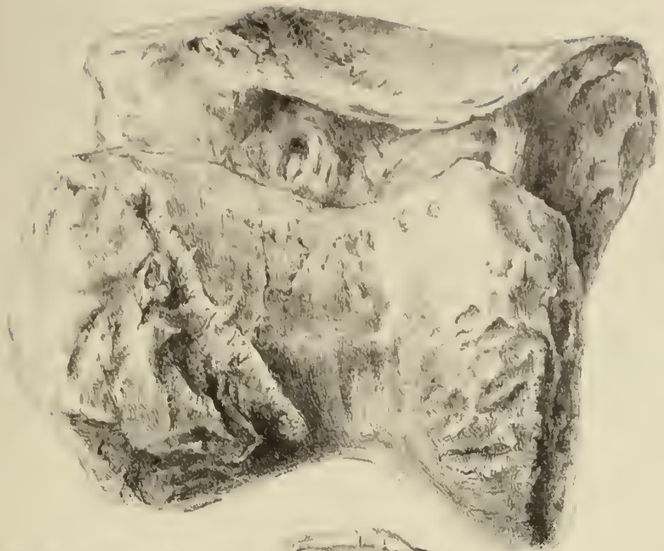
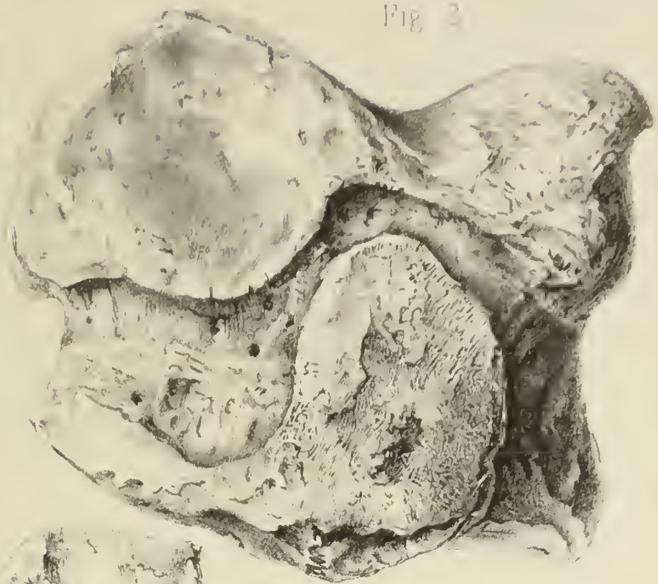


Fig. 3.



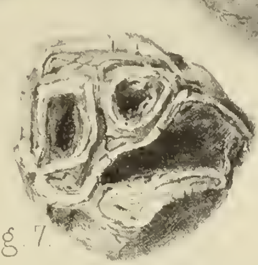


Fig. 7.

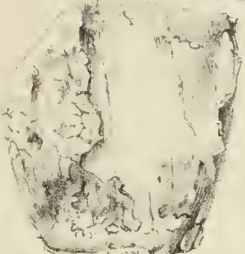


Fig. 6.

Fig. 4.

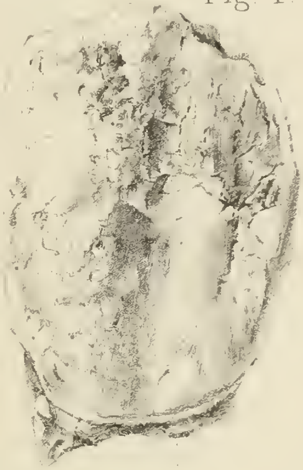


Fig. 10.

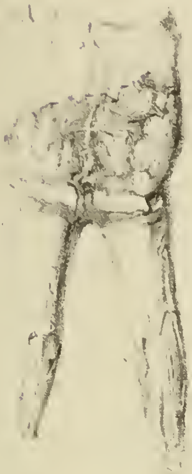


Fig. 11.

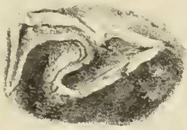


Fig. 8.

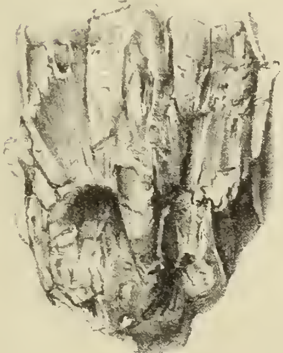
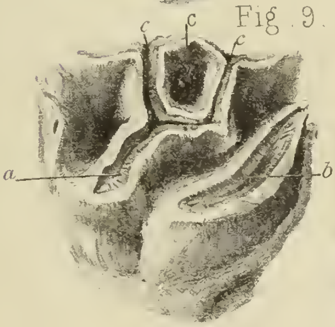


Fig. 9.



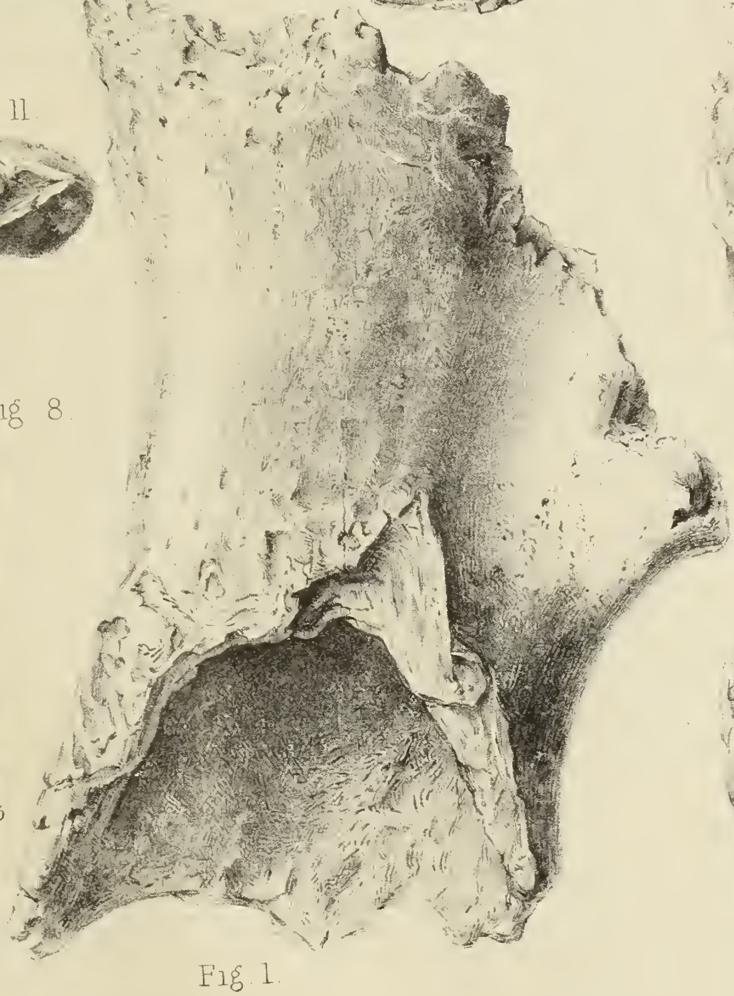
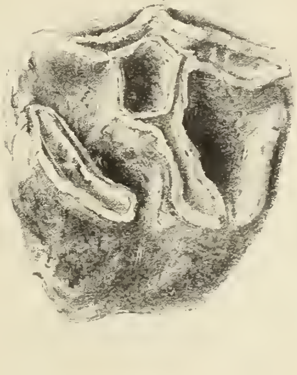


Fig. 1.

Fig. 5.



E. M. B. ad nat. del.
W. H. Wesley, Auto. Lith.

M'clure & Macdonald, Lith. London.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

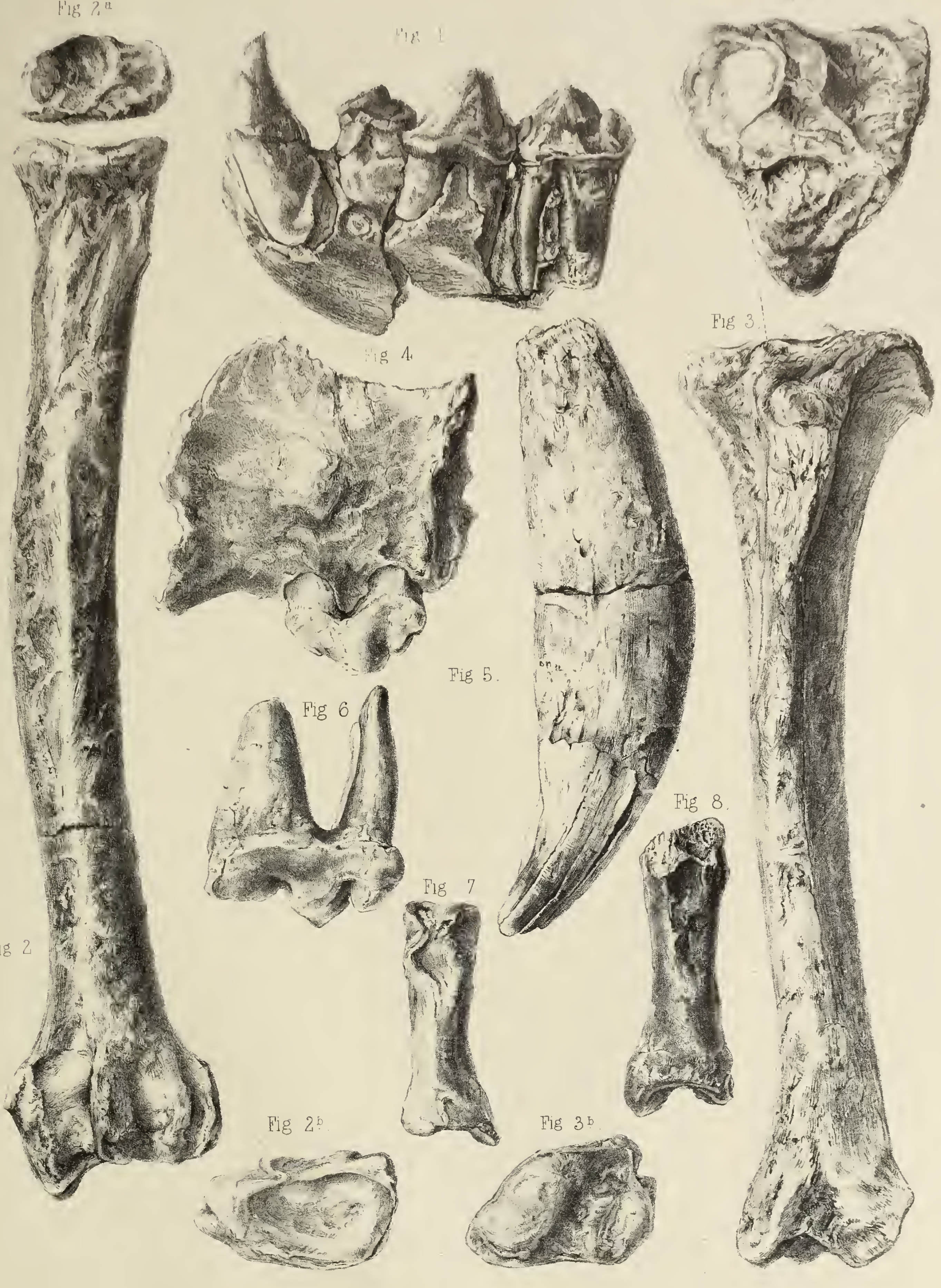
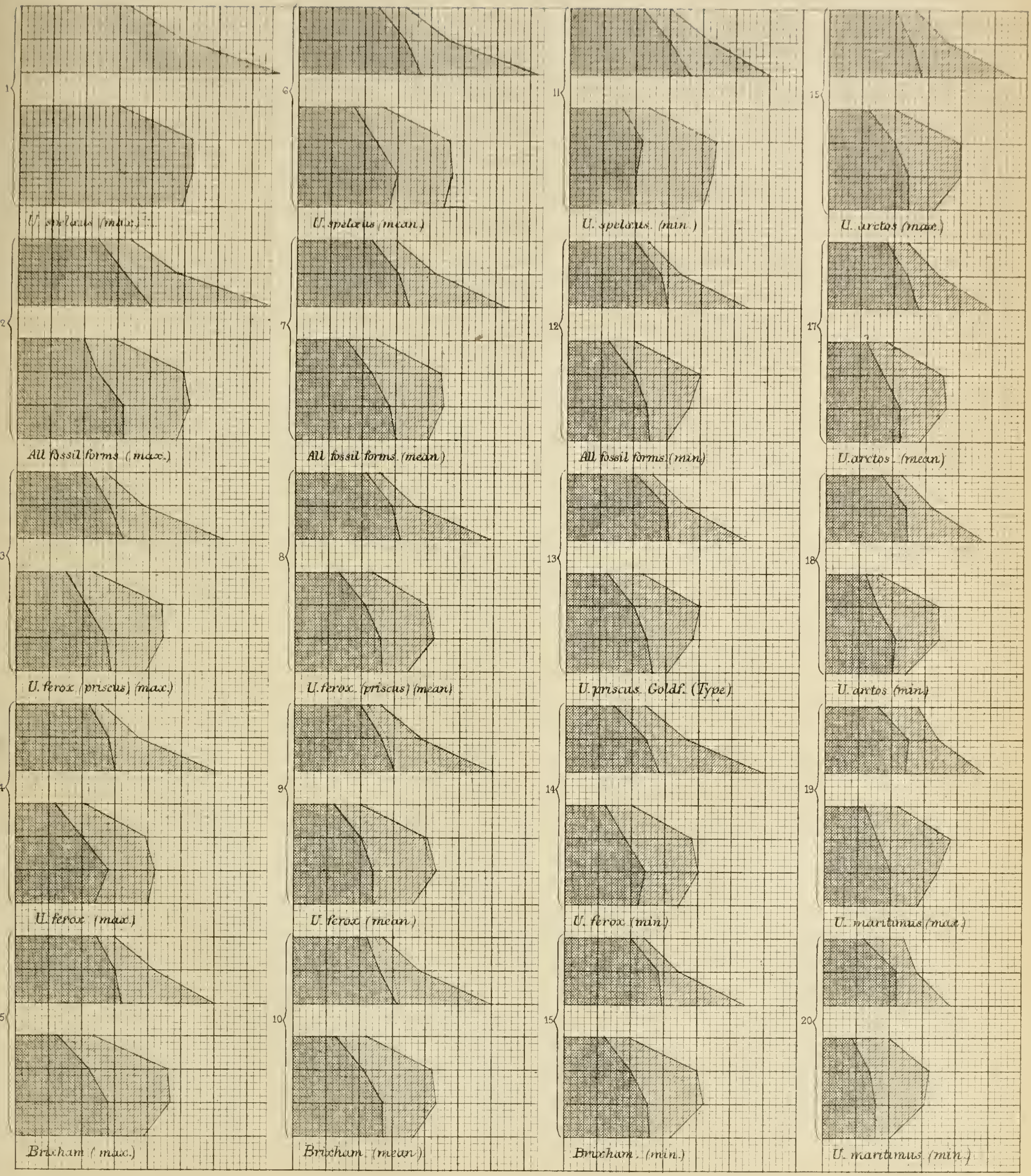


Fig 2a
Fig 1
Fig 3a
Fig 4
Fig 3
Fig 5.
Fig 6
Fig 8.
Fig 7
Fig 2
Fig 2b.
Fig 3b.

LIBR
OF THE
UNIVERSITY of ILLINOI



1 *U. spelæus (max.)*

2 *All fossil forms (max.)*

3 *U. ferox (priscus) (max.)*

4 *U. ferox (max.)*

5 *Brixham (max.)*

6 *U. spelæus (mean.)*

7 *All fossil forms (mean)*

8 *U. ferox. (priscus) (mean)*

9 *U. ferox (mean.)*

10 *Brixham. (mean)*

11 *U. spelæus. (min.)*

12 *All fossil forms (min)*

13 *U. priscus. Goldf. (Type)*

14 *U. ferox (min)*

15 *Brixham. (min.)*

15 *U. arctos (max.)*

17 *U. arctos (mean)*

18 *U. arctos (min.)*

19 *U. maritimus (max.)*

20 *U. maritimus (min.)*

Odontograms of Ursus

W West & C° [illegible]

LIBR
OF THE
UNIVERSITY OF ILLINOIS

XV. *On a new Locality of Amblygonite, and on Montebrasite, a new Hydrated Aluminium and Lithium Phosphate.* *By* M. A. O. Des Cloizeaux, *Member of the Institute of France. Communicated by Professor* W. H. Miller, *Foreign Secretary R.S.*

Received November 27, 1871,—Read February 20, 1873.

Until last year the Amblygonite from the neighbourhood of Penig in Saxony had alone been analyzed—namely, by Berzelius and by Rammelsberg. The beautiful transparent or translucent specimens found in 1862 at Hebron, Maine, U.S.A., had been merely tentatively examined by Prof. Brush, who announced the presence in them of lithia in considerable quantity. Their similarity to the Penig mineral, however, led to their being looked on, without further investigation, as Amblygonite. These specimens, less rare and more transparent than those from Saxony, had enabled me in 1863 to determine their crystalline system and their birefringent optical characters*.

In 1870 M. Moissenet, mining engineer, sent me a mineral which had been found in considerable quantities in the tin vein of Montebras (Creuse). This mineral, though resembling the Amblygonite of Hebron, appeared to me so far to differ from it in its optical characters and in the composition, deduced from an imperfect analysis made in the laboratory of the École des Mines, as to justify my distinguishing it under the name of Montebrasite †.

Afterwards, towards the close of 1871, I received from M. Moissenet another specimen coming from Montebras, which presented all the characters of the American Amblygonite, and which consequently was easily distinguished from the Montebrasite, as I showed in my notice read to the Academy on Nov. 27, 1871.

Subsequently to the publication of this note, the analyses made by Pisani (Comptes Rendus des Séances de l'Académie des Sciences, séance du 26 Déc. 1871, tom. lxxiii. p. 1479), by Kobell (Sitzungsberichte der bayerischen Acad. der Wiss., Feb. 3, 1872), and by Rammelsberg (Berichte der deutschen Chem. Gesellsch. Berlin, 26 Feb. 1872, No. 3, p. 78) proved the identity, in point of chemical composition, of the Montebrasite of Montebras and the Amblygonite from near Penig. This identity ought in fact to exist in the Saxon variety, for I have lately satisfied myself that a plate cut from a Penig specimen, in a direction, as nearly as might be, perpendicular to the two principal cleavages, presents the same optical characters as do plates cut from some specimens from Montebras, which will be discussed presently. But this is not the case with respect to the Amblygonite from the State of Maine, nor with that from Montebras, the analysis of which has been made by PISANI; since, as the pyrognostic characters led one to foresee, these differ from the Amblygonites of Saxony and Montebras (which I had previously named Montebrasite) by the absence of soda, by the preponderance of lithia, and by the presence of a notable amount of water, while at the same time the minerals resemble one another in their almost equal proportions of phosphoric acid and of alumina.

---

* Comptes Rendus des Séances de l'Académie des Sciences, tom. lvii. p. 357.

† Comptes Rendus des Séances de l'Académie des Sciences. Séances des 31 Juillet et 27 Nov. 1871, tom. lxxiii. pp. 306 & 1247.

If we leave the water out of the question, the soda seems here to play the part which I have attributed to it in certain *pseudodimorphous* bodies, and especially in the sulphate of potash*; except that Amblygonite and Montebrasite belong to the same crystalline system, and their optical characters alone present complete incompatibility, while the crystals of sulphate of potash occur in two nearly resembling but incompatible types, according as they do or do not contain soda.

It results from what has been above stated, that the differences which Amblygonite and Montebrasite present in their physical and chemical characters appear to be sufficiently decided† to compel us to treat these substances as belonging to nearly related but distinct species—the one anhydrous, the other hydrated. We shall retain the name Amblygonite for the sodiolithic species first discovered at Penig by BREITHAUPT, and accordingly the white or violet-tinted lamellar masses abundant at Montebras will be included under it‡; while the hydrated and entirely lithic species, comprising the beautiful laminar specimens and the crystals from Maine, as well as some greenish masses from Montebras, still very rare, will be embraced under the name Montebrasite, which I had at first proposed for the first masses from Montebras, an erroneous analysis of which had been furnished, as before mentioned, by the laboratory at the École des Mines.

In the following pages I shall give a detailed description of the principal crystallographic and optical characters, as well as the analyses of the two species.

I. *Anhydrous Sodiolithic Species—Amblygonite.*

The Amblygonite of Montebras, designated as Montebrasite in my communication to the Academy of Sciences of Nov. 27, 1871, has only been met with in laminar masses, sometimes opaque and of a dull white, sometimes more or less translucid, and in parts even transparent and with a faint tinge of violet. These masses exhibit only two cleavages, presenting nearly the same degree of facility, but yielding surfaces so uneven and rough that, for measuring their inclination, one has to isolate small portions, as little uneven as possible. But, even with this precaution, one can never obtain sufficiently perfect reflections to afford exact measurements ; and it is only by repeating these measurements on a great number of fragments, and by taking the mean of these, that I have succeeded in determining with tolerable exactness the incidence of the two cleavages to be 105° 44′. Close observation shows, furthermore, that the sharpness of the reflected images is generally a little greater on one of the surfaces of cleavage than on the other, which would induce one to suppose that they do not both belong to equivalent crystallographic planes; the difference, however, is so small that one does not notice it at first, still less can it be compared to that which I have pointed out as distinguishing the face *p* (with pearly cleavage) from the face *m* (the vitreous cleavage) of the Montebrasite of Hebron in the State of Maine*.

---

* "Mémoire sur pseudodimorphisme de quelques composés naturels et artificiels," Annales de Chimie et de Physique, 4^{me} sér. tom. i. p. 313.

† I would further remark, as a distinctive feature of secondary importance, that the Montebrasite (the former Amblygonite) from the United States and that from Montebras present at least three distinct cleavages, parallel to the faces of an oblique-angled parallelepiped; while on none of the specimens of Amblygonite (the former Montebrasite), so many of which have passed through my hands, have I ever been able to detect more than two cleavages.

‡ These are the masses which are designated as Montebrasite in my notice in the 'Comptes Rendus' of 27 Nov. 1871, whereas the greenish specimen from Montebras is described as Amblygonite. I propose this inversion of the names out of respect to the priority of the name Amblygonite.

The insufficiency of the geometrical characters naturally led to the inquiry whether the study of some of its optical properties might not enable me to determine the crystalline type of the mineral; and this investigation, which presents certain special difficulties arising from the small extent of the transparent portions and the presence of numerous twin plates even in the specimens that to all appearance are the most homogeneous, has proved that, without doubt, the laminar masses of Montebras must be referred to the triclinic system.

In order better to compare the points of analogy or of difference which distinguish Amblygonite and Montebrasite (minerals composed of the same constituent elements but in different proportions), I have assumed, in the first of these minerals, that the less perfectly reflecting cleavage took place parallel to the base *p*, and the more perfectly reflecting cleavage parallel to the face to the left, *m*, of an oblique-angled parallelepiped, of which the face to the right *t*, and the relative dimensions are still unknown. The angle *p m* of Amblygonite equals 105° 44′, which differs by only 44′ from the corresponding angle in Montebrasite.

The optical investigation was commenced by the examination of thin plates cut perpendicularly to the two cleavages; and it served to establish that these plates were obviously oblique to the plane of the optic axes. In order to obtain plates as perpendicular as was possible to this plane and to the bisector of the acute angle of the axes, it became necessary to arrange a sort of tentative method by the aid of the polarizing microscope†.

---

* "Sur les propriétés optiques biréfringentes et sur la forme crystalline de l'amblygonite," Comptes Rendus des Séances de l'Acad. tom lvii. p. 357.

† All these tentative sections have been effected by M. H. Soleil with his well-known patience and skill. The working of these plates of Amblygonite (formerly Montebrasite) is all the more delicate since the best specimens that I obtained of M. Moissenet would not allow of plates being cut of a thickness greater than $\frac{3}{4}$ of a millimetre, in order to present the transparency necessary for the subsequent execution of the slight modifications which the polarizing microscope might prove their worked surfaces still to require.

The result of these tentative trials proved that the most perfect plates were those the surfaces of which made nearly equal angles with the two cleavages (affording a mean result of 99° 8′ with *m* and 99° 25′ with *p*). The optic axes are situated in a plane which divides into two very unequal parts the acute angle=74° 16′ of the two cleavages. This direction is entirely different from that which I have found for Montebrasite (formerly Amblygonite) of Hebron and of Montebras, in which the plane of the axes lies in the obtuse angle of 105° formed by the two principal cleavages*.

With regard to the exact orientation of this plane, I have deduced it from that which it presents in the natural macles of which all the plates of Amblygonite of Montebras which I have examined are constituted, and which result from the interposition in the midst of their mass of twin lamellæ that bisect almost exactly, the one set the obtuse angle of 105° 44′, the other the acute angle supplementary to it. These lamellæ, which are often met with on the same specimen, in which they cross one another at an angle of very nearly 90°, are sometimes so thin and so numerous that they convert the whole mass into a network with close meshes, to all appearance rectangular, in which the coloured rings are only visible in the polarizing microscope at a few isolated points. Fortunately this is not always the case, and plates are pretty often found which are referable to one of the four subjoined types, and which offer more or less facility for the study of the optical doubly refracting properties of the substance.

Fig 1 (p. 579) represents those plates which are divided into slices, triangular or trapezial in section (1, 3, 5, 7, 9, &c.), which are more or less homogeneous, by a series of bands which are generally narrow (2, 4, 6, 8, &c.), parallel to one another, and very nearly parallel to the bisector-plane of the acute angle of 74° 16′; in these bands we may recognize, by the fibrous aspect which they exhibit even under illumination by ordinary light, a number of excessively thin lamellæ. Thus, while in the sectional figures indicated by an odd number the disposition and dispersion of the coloured rings can be studied in the polarizing microscope, it is only in some narrow regions of the bands indicated by the even numbers that one can examine them. This examination suffices, however, to show that whenever the section has been so successfully made as that the plane of the optic axes is as nearly normal as possible to the worked surface in the case of the slices with the odd numbers, it still remains in a very slight degree oblique to the plane in the case of those with the even numbers. In the latter case the orientation of this plane is only to be explained by the existence of lamellæ parallel to the edge *p m* which have undergone a revolution of 180° round an axis within a few minutes of being perpendicular to that edge. A great number of observations were made with an apparatus in which the two Nicols were crossed, on the maximum extinction of the light in the bands successively even and odd; and these gave the result, that the plane of the optic axes in the bands of the former order formed, with that in the latter case, a mean angle of 58° 22′.

---

* It will be seen further on that the Montebrasite which I have lately found among the specimens from Montebras presents the same optical characters as that from Hebron in the State of Maine.

The presence of the numerous lamellæ of which I have spoken ought, one would suppose, to be evidenced on the cleavages *p* and *m* by fine striæ parallel to their mutual intersection; of these, however, I have never been able to find the smallest trace in the midst of the irregularities which the surfaces of these cleavage-planes present. This is no doubt due to the lamellæ, which are so thin as not even to produce the phenomena of the colours of thin plates, not permitting of our distinguishing from *p* and *m* their faces in the turned position ≋ and ≈, the inclination of which on the former planes has the calculated angle *p* ≋ =179° 56′ and *m* ≈=180° 4′, a difference alike unappreciable to the eye and to direct measurements*.

Figures 2 and 4 present plates compounded of two great divisions twinned round an axis perpendicular to a surface of assemblage which is contained in the obtuse angle *p m*=105° 44′, and gave to direct measurement a mean angle of 52° 2′ with *p*, and consequently an angle of 53° 42′ with *m*. The two figures only differ in other respects from one another in the relative dimensions of their constituent portions; and these dimensions may vary to any extent, according to the spot where the plane of assemblage may meet the cleavages *p* and *m*. Each of these portions is furrowed by fibrous bands, which are sometimes reduced to mere threads and present an orientation like that of fig. 1, and by lamellæ, generally very thin, which are parallel to the plane of assemblage.

The tessellated pattern, often very complex, which is produced by the two systems of lamellæ is perfectly visible in polarized light with parallel rays; and one can even obtain by photography† magnified images in which the threads situated in the obtuse angle may be recognized as being in general more blended and less undulated than are those situated in the acute angle. The mutual inclination of the lamellæ which belong to the two systems has been approximately estimated at 89° 12′ and 90° 48′ upon plates cut nearly normal to the plane of the optic axes. By combining with the angle of 58° 22′ found on the twins of the type No. 1 this number 89° 12′, an inclination of 123° 14′ may be deduced for that between the plane of the optic axes belonging to one region of the plate and that belonging to the other region of it. (The measures that were made with plates similar to those of figs. 2 and 4 vary between 122° 42′ and 123° 31′.) As for the adjustment of the two regions of the section with regard to the plane of the optic axes and to their bisector, when this has been made as accurate as possible with regard to the one it is slightly inaccurate with regard to the other, exactly as is the case with the twins similar to those in fig. 1.

On the laminar masses from which I obtained the plates of the types 2 and 4 I have occasionally observed indications of the line in which the plane of assemblage meets the cleavages in the form of a slight ridge (see that of fig. 2), or of striations which are only visible in a bright light, and which correspond to the groove drawn to the right on the plane on the back of the section of fig. 4: the reentering angle *md* was found to be 181° to 182°; by calculation it should be 181° 40′. When the lamellæ parallel to the plane of assemblage of figs. 2 and 4* are grouped in bands of a certain width, their arrangement is that represented in fig. 3.

---

* The same fact may be observed in crystals of calcite and of aragonite traversed by twin lamellæ, where the trace of these ceases to be visible upon the faces at which they come out, when they present more than a certain degree of thinness.

† I am indebted to M. Cornu for images of these obtained by means of a small solar microscope in the laboratory of the École Polytechnique.

Though the determination of the crystallographic data for Amblygonite must necessarily be incomplete until at least a third face has been discovered not lying in the same zone with the two principal cleavages, I have given in the following Table a *résumé* of the measured and of the calculated incidences, the correctness of which may be looked upon as fairly satisfactory. For brevity, I indicate by S the surface which has been worked perpendicularly to the plane of the optic axes and to the bisector of their acute angle, by H the twin plane lying in the obtuse angle of the two cleavages, and by L the plane of the laminæ lying in their acute angle. At the point in which the three edges $\frac{m}{S}$, $\frac{S}{p}$, $\frac{p}{m}$ (figs. 1, 2, and 3) meet one another the plane angles are:—

Plane angle of *m* = 97° 17′ 20″.
" " *p* = 96 55 3.
" " S = 104 34 49.

		Calculated.		Observed.
		° ′		° ′
m : S		......	....	99 8 mean.
p : S		......	....	99 25 "
p : *m*		......	....	105 44 "
p : H (fig. 4)		......	....	52 2 "
m : H (fig. 2)	=	126 16 53 44	....	" "
p : *d* (fig. 4)	=	104 4	....	104 32 "
m : *u* (fig. 2)	=	107 28	....	"
m : *d* (figs. 2 and 3)	=	178 20 salient	....	"
m : *d* (fig. 4)	=	181 40 reentering	....	181 to 182°
S superior : H (figs. 2, 3, and 4)	=	89 36	....	"
S inferior : H (figs. 2 and 4) ..	=	90 24	....	"

---

* The twin plane contained in the angle of 105° 44′ may be conceived as being parallel to an hypothetical face *c*′, which would truncate the posterior edge to the right of the parallelepiped, of which we only as yet know the planes *p* and *m*, with an inclination upon *p* of 127° 58′. According to M. Breithaupt, there should be a different cleavage corresponding to a similar face on the specimen of Amblygonite from Penig. In my note of date 1863, I had thought I could make use of the inclination of this cleavage upon *m* for the calculation of the height of the primitive form of Montebrasite (at that time supposed to be Amblygonite) from Hebron. As will be seen further on, Mr. Dana has established the presence of a face *c*′ for the large crystals of Montebrasite found at Hebron; but the inclinations appear very different from those which M. Breithaupt obtained on the Amblygonite from Penig.

	Calculated.		Observed.
	° ′ ″		
edge $\frac{p}{m}$: edge $\frac{S}{H}$ …………… =	101 39 33		
p : L (fig. 1) …………… =	37 6		
m : L (fig. 1) …………… =	37 10		
p : m (fig. 1) …………… =	179 56 salient.		
m : p or d : m (figs. 1 and 4) =	180 4 reentering.		
S : L superior …………… =	101 39 50		
S : L inferior …………… =	78 20 10		
L : H …………………… =	89 8 90 52		
edge $\frac{S}{L}$: edge $\frac{S}{H}$ (figs. 1 and 2) =	……… 90 48	………… …………	89° 12′
edge $\frac{S}{L}$: edge $\frac{p}{m}$ …………… =	89 46 90 14	………… …………	,, ,,

Fig. 1.

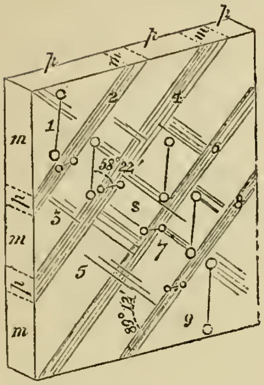


Fig. 2.

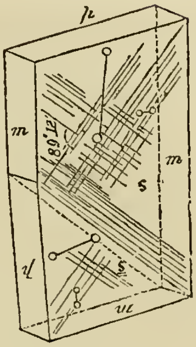


Fig. 3.

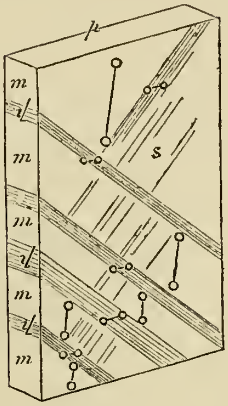
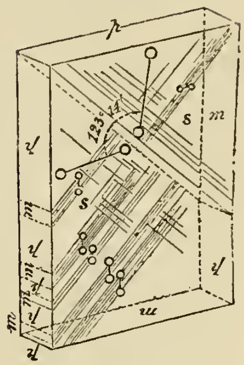


Fig. 4.



The plane of the optic axes makes an angle of $\begin{cases} 12° 29′ \text{ with } m \\ 67° 13′ \text{ with } p \end{cases}$. In the twins fig. 1 the plane of the axes of 1, 3, 5, 7, 9 meets that of 2, 4, 6, 8 at an angle of 58° 22′ (which is the mean of several observations). In the twins figs. 2 and 4 the plane of the axes of one region intersects that of the other region at an angle of 123° 14′, by observation 122° 42′ to 123° 31′. The bisector of the acute angle of the axes is *negative*, and it is very little removed from coincidence with the twin plane H, and makes respectively angles of 11° 39′ 58″ with the edge $\frac{p}{m}$, 53° 26′ 31″ with the edge $\frac{p}{S}$, and 51° 8′ 18″ with the edge $\frac{m}{S}$. The mean index was measured on a prism of 59° 23′, the refracting edge of which is almost exactly normal to the plane of the optic axes; I have found $\beta = 1{\cdot}594$ (the yellow sodium ray).

The apparent separation of the axes admits of the two corresponding systems of coloured rings being both visible in air. This separation, though sufficiently constant in the different regions in the same plate, being about 86°, is, however, as low as about

71° in some specimens. By operating in air and in oil[*] on two plates tolerably perpendicular to the plane of the optic axes and to their acute bisectors, I obtained at 20° C. for the first plate:—

$$\left.\begin{array}{l} 2\,E=86^\circ\,23' \\ 2\,H=55\ 18, \text{ whence } 2\,E=86^\circ\,28' \end{array}\right\}\text{Red ray.}$$

$$\left.\begin{array}{l} 2\,E=86\ 21 \\ 2\,H=55\ \ 8, \text{ whence } 2\,E=86\ 19 \end{array}\right\}\text{Yellow ray (soda).}$$

For the second plate:—

$$\left.\begin{array}{l} 2\,E=70^\circ\,54' \\ 2\,H=46\ 20, \quad \text{ whence } 2\,E=71^\circ\ \ 0' \end{array}\right\}\text{Red ray.}$$

$$\left.\begin{array}{l} 2\,E=70\ 32 \\ 2\,H=45\ 59\ 30'', \text{ whence } 2\,E=70\ 32 \end{array}\right\}\text{Yellow ray.}$$

It is evident from these numbers that the actual dispersion of the axes is feeble, presenting $\varrho > v$[†]. We come to the same conclusion by observing in air and in oil the fringes of the hyperbolas which traverse the two systems of coloured rings at an angle of 45° to the plane of polarization, and which present a reddish yellow on the *inside* and blue on the *outside*. A careful scrutiny further reveals that these fringes seem to have a slightly more decided colour in the one system than in the other, but in both the rings present to all appearance the same form. In the plane of polarization, the transverse bars of the central ring in each system are bordered by colours, the distribution of which in contrary directions indicates very distinctly a twisted dispersion ("dispersion tournante"): these colours appear furthermore to be slightly more definite round one of the bars than round the other; but so slight a difference would not authorize us to admit the existence of a small amount of inclined dispersion, the combination of which with the twisted dispersion ("dispersion tournante") would suffice to characterize a substance belonging to the triclinic system, unless the plates of Amblygonite from Montebras (formerly Montebrasite) possessed perfect homogeneity[‡]. The doubly oblique form of this mineral can, in fact, only be established in an incontestable manner by the obliquity of the cleavages *p* and *m* on the plane perpendicular to that in which the optic axes lie, because this obliquity is absolutely incompatible with a clinorhombic form, in which the plane of symmetry would be perpendicular to the plane of the optic axes and to the bisector of their acute angle, in which, furthermore, the twisted dispersion would be very strong.

---

[*] The oil I used was very viscous, and had the indices $n_r=1{\cdot}476$; $n_i=1{\cdot}478$.

[†] In Montebrasite (formerly Amblygonite), State of Maine, one has, on the contrary, $\varrho < v$ on either side of the acute bisector; so that this opposite character in the proper dispersion of the optic axes would suffice to distinguish Amblygonite from Montebrasite, since it forms a distinctive character of the highest importance in crystallized substances, and seems to be the most constant of all their properties as optically birefringent substances. In fact there is no example of a single well-defined species of a natural or artificial product presenting in different specimens optic axes with opposite dispersions, provided that these axes are situated in the same plane; and this is true whatever may be the variations in their physical and chemical characters. It is only when the axes pass from one plane into a second perpendicular to it, as happens in orthose, heulandite, and other minerals, that any change takes place in the relative positions of the axes corresponding to the red rays with regard to the axes which correspond to the blue.

[‡] Under the same circumstances Montebrasite of Hebron and Montebras presents a *horizontal* dispersion in combination with a well-marked *inclined* dispersion. The phenomena to which those different kinds of dispersion give rise in the coloured rings are described and figured in my "Mémoire sur l'emploi du microscope polarisant," in the 'Annales des Mines' for 1864, tom. vi. 6th series.

Heat changes the angle of separation of the optic axes by diminishing it in a sensible degree. A plate only slightly oblique to their plane gave in air for the red rays

$$2\dot{E}=86°\ 26' \text{ at } 14°C;\ 82°\ 16' \text{ at } 120°\ C.$$

Between these two temperatures one of the axes moved about $2\frac{1}{3}$ times faster than the other, the first having advanced towards the bisector by 2° 56′, while the second had only moved 1° 14′; the bisector, therefore, had moved from its initial position, and had been displaced by 0° 51′ towards the same side as the axis which had made the least progress*.

When I published my first notice, "Sur les propriétés optiques biréfringentes et sur la forme crystalline de l'amblygonite," Comptes Rendus des Séances de l'Académie des Sciences, tom. lvii. p. 357, I had only been able to place under the polarizing microscope a very small plate parallel to the more difficult cleavage *m* of the Penig variety; consequently I was only able to examine the optical phenomena in this case in a very incomplete manner. Having lately again examined a plate nearly perpendicular to the edge of the intersection of the two unequal cleavages *p* and *m*, I could perceive that around the *negative* acute bisector the plane of the optic axes is in the acute angle $p\ m=74°\ 16'$, that the dispersion proper to the axes indicates $\varrho > v$, and that there is also a very observable *twisted* dispersion combined with a slight *inclined* dispersion. In oil the separation of the optic axes is about $2\ H=56°\ 30'$ (in white light). These characters belong to Amblygonite (formerly Montebrasite) of Montebras. The only difference that the specimens from Penig present, as compared with those from Montebras, is that their physical constitution is more homogeneous, and that they are not traversed, as the latter are, by twin plates.

Amblygonite melts easily in a simple alcoholic flame, without decrepitation and with a slight bubbling, into an opaline white blebby glass. Before the blowpipe it communicates to the flame a reddish-yellow coloration, owing to the soda and lithia which it contains. This coloration enables one immediately to distinguish it from Montebrasite, which contains only lithia, and consequently only yields a flame of a rich carmine tint.

The composition of Amblygonite is established by the following analyses:—

---

* A plate of Montebrasite from Hebron heated to about 100° exhibits no change in the appearance of its coloured rings.

	Amblygonite of Montebras.			Amblygonite of Penig.
	Pisani.	Kobell.	Rammelsberg.	Rammelsberg.
Fluorine	8·20	9·00	10·06	9·44
Phosphoric acid	46·15	45·91	48·55	48·00
Alumina	36·32	35·50	36·36	36·26
Lithia	8·10	6·70	7·96	6·68
Soda	2·58	5·30	0·93	3·29
Potash	....	....	0·40	0·43
Lime	....	0·50	....	....
Oxide of manganese..	0·40	....	....	....
Loss on ignition	1·10	0·70	....	....
Silica mixture	....	0·60	....	....
	102·85	104·21	104·26	104·10
Density........	3·09 to 3·10	....	....	3·11

II. *The Hydrated Lithic Species—Montebrasite.*

I received quite recently (November 1871) from M. Moissenet a new specimen obtained from the mine of Montebras, from the midst of the masses which I had at first called Montebrasite (now Amblygonite), and distinguishable by its possessing an unwonted transparency rare in that substance. A cursory examination sufficed to show that I had not to deal in it with the old Montebrasite (*i. e.* Amblygonite), but rather with the mineral supposed to be Amblygonite, although then not analyzed, and of which the finest specimens, which presented the form of laminar masses or of coarse crystals *, had been found hitherto at Hebron, State of Maine, U.S.A.

The new specimen from Montebras is of a pale green colour in its more transparent parts, and presents the three principal cleavages p, m, t which I have recognized in the masses from Hebron, and of which the first is easily obtained, and yields an unbroken surface with a somewhat pearly lustre, while the second, less easily obtained, results in broken surfaces vitreous in lustre ; and the third is a still more difficult cleavage, and is recognizable by small reflecting surfaces scattered among rough surfaces of fracture.

---

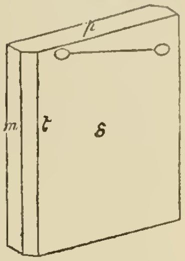
* In the 5th edition of his 'System of Mineralogy,' p. 545, Mr. Dana has figured a large crystal of Montebrasite of Hebron, the forms of which, referred to the oblique-angled parallelepiped produced by the three principal cleavages p, m, t, and which I adopted in 1863 as the primitive form of amblygonite, now Montebrasite, seem as if they ought to be expressed by the simple symbols m, t, g^1, g^4, $x=(f^{\frac{1}{2}}\, c^{\frac{1}{4}}\, g^1)$. Unfortunately the measure indicated by Mr. Dana could only be approximately made in consequence of the inequalities of the surface of the crystal, and would not justify our using them as means of determining with exactitude the dimensions of the primitive solid.

Thus if we take for the fundamental data the numbers $m\ t=135°\ 30'$, $p\ m=105°$, $p\ t$ forwards $=88°\ 30'$ (exact measures taken on planes of cleavage), $t\ g'$ adjac.$=73°\ 20'$, $m\ c'$ adjac.$=131°\ 50'$ (approximate measures obtained on the crystals), we obtain for the forms g^4 and $x=(c^{\frac{1}{2}}\, f^{\frac{1}{4}} g^1)$, by calculation, incidences so far divergent from those obtained by observation, namely a difference of from 3° to 4°, that it would be better to wait for fresh observations made upon more perfect crystals. Agreement between the results of calculation and direct measurement is only to be obtained by having recourse to symbols for which the expressions are so complicated as to be altogether unusual in the triclinic system.

Some good measurements, made on very smooth surfaces of the two former cleavages, yielded exactly the angle $p\ m=105°$. For the other incidences I obtained the approximate values $m\ t=135°$ to $136°$, $p\ t=89°$ to $89°\ 15'$.

The transparency that suitably chosen fragments acquire when cut into thin plates has led me to modify a little the orientation of the plane of the optic axes and of their bisectors which I found upon the Hebron specimen. By means of artificial twins formed of two plates, each of which has been worked perpendicular to the two cleavages p and m, and which were united by their faces p, I have been enabled to satisfy myself that the plane of the optic axes situated in the obtuse angle $p\ m=105°$ traverses the edge $\frac{p}{m}$, but that it is not quite normal to m, as I had at first supposed, since it gives mean angles of about 82° with m and 23° with p. By the employment of a similar process with an artificial macle made from the fragments from Hebron, I have obtained numbers that are almost identical with those just given.

Fig. 5.



The bisector of the acute angle of the optic axes is negative, and does not seem to be exactly parallel to the edge $\frac{p}{m}$; but its exact direction in the plane which contains both it and the optic axes cannot be determined with great exactitude on account of the difficulty of obtaining plates which are exactly perpendicular to it, and more particularly on account of the great separation of the axes even in oil*.

This separation, which prevents the centre of the coloured rings being ever seen in air, is essentially variable, in consequence of the irregularity of the interlacing laminæ in the interior, the existence of which is evidenced in particular on the surfaces of the nacreous cleavages by a waviness or by slight reentering angles visible in a bright light. I have found upon some of the plates for the acute angle of the optic axes for red in oil between 14° and 20° C.,

$$2H_{a.r}=95°\ 48';\ 99°\ 39';\ 101°;\ 102°;\ 102°\ 38'.$$

The obtuse angle containing the positive bisector gave measurements

$$2H_{o.r}=102°\ 50';\ 104°\ 21';\ 106°\ 10'.$$

---

* In the neighbourhood of the bisector of the obtuse angle of the optic axes difficulties of the same kind present themselves. It is, in fact, established by the simultaneous maximum extinction of the light in both parts of a twin formed of two plates parallel to m, of which the faces p are brought together in opposite positions, that the plane of the axes is parallel to the edge $\frac{p}{m}$, which should be a little oblique to the *positive* bisector, inasmuch as the coloured rings seen in oil through the faces m do not seem to be at the same distance from the normal to these faces. The position of the bisector itself could not, however, be precisely determined; for even when plates inclined at about 7° or 8° upon m, as nearly as possible perpendicular to the plane of the axes, were used, it was scarcely possible to measure with any exactitude in oil the angle that each of them makes with a normal common to the plates and to the edge $\frac{p}{m}$. Some experiments led to the conclusion that this normal made with the positive bisector an angle of about 4° to 5°.

In some specimens the *interior* or real angle of the axes is 90°, and in oil is equal to 102° round each of the two bisectors. In other specimens an interchange seems to occur between the bisector of the acute and that of the obtuse angle, their respective signs remaining otherwise the same; thus in two plates taken from the same fragment,

$$2H_r = \begin{matrix} 108^\circ\ 24' \\ 97^\circ\ 5' \end{matrix}\left\{\begin{matrix}\text{the angle containing the } \textit{negative} \text{ bisector.} \\ ,, \qquad ,, \qquad \textit{positive} \qquad ,, \end{matrix}\right.$$

These different variations in the separation of the optic axes are of course associated with greater or less irregularities in the form of the coloured rings, and of the hyperbolas which traverse them; but the one invariable feature is seen in the different kinds of dispersion which I have already remarked on in the specimens from Hebron. Direct measurement indicates $\varrho < v$ to be the *proper* dispersion of the axes containing the negative bisector. This dispersion, strongly marked in one of the systems of rings of which the hyperbola examined at 45° to the plane of polarization is bordered by bright blue in the inside and by red on the outside, is on the contrary very weak in the other system, in which the borders of the hyperbola present, both on the outside and in the inside, blue tints that are hardly distinguishable.

Examined in the plane of polarization, the transverse bars of the central ring of the two systems give evidence of the existence of *horizontal* dispersion by the symmetrical arrangement of their borders; while these borders, on the other hand, exhibit colours that are distinctly more decided in the one system than in the other, but the difference is the inverse of that which is seen in the position 45° to the plane of polarization.

The characters which have been described thus show that in Montebrasite (formerly Amblygonite) of Montebras, as in that from Hebron, there coexists with the horizontal a well-marked inclined dispersion, a combination peculiar to crystals of the triclinic system. About the positive bisector the inclined dispersion is united to the twisted dispersion.

Montebrasite from Montebras, and that from Hebron, contain only lithia; hence they communicate a colour of a brilliant carmine-red to the flame of the blowpipe, in which they melt with great readiness into a white enamel with a distinct decrepitation. In a closed tube they disengage a water which corrodes the glass. Their loss under the action of the heat is observably greater than that of Amblygonite, while on the other hand their density is lower. M. PISANI has found for the composition of the laminated specimens from Hebron and of the green variety from Montebras:—

	Hebron.	Montebras.
Fluorine	5·22	3·80
Phosphoric acid	46·65	47·15
Alumina	36·00	36·90
Lithia	9·75	9·84
Water	4·20	4·75
	101·82	102·44
Specific gravity	3·03 (PISANI) 2·999 (DAMOUR)	3·01 (PISANI) 2·977 (DAMOUR)

Note upon Wavellite of Montebras.

Wavellite, in the form of thin coatings, presenting a mammillated and fibrous structure, forms a layer over almost all the fissures that occur in the Amblygonite of Montebras; and sometimes even the latter is seen to lose its laminar structure, to become white and opaque, and to pass insensibly into the former mineral. When the coatings are somewhat thick and contain cavities, radiated spherules are found in them, which are composed of long thin needles with brilliant terminations. These needles exhibit a vertical prism that is deeply grooved but cannot be measured; its acute edges are truncated by the diagonal face g^1, and surmounted by a rhomboidal octahedron, two culminating edges of which are replaced by minute faces of the bevel a^1. Professor MILLER, in his ‘Elementary Introduction to Mineralogy,’ has figured two solids of a similar kind, $b^{\frac{1}{2}}$ and e_3, both of which are situated in the zone g^1 a^1, like the terminal octahedron of the needles of Montebras; but their angles of incidence do not at all agree with those that I have succeeded in measuring with some exactitude. Moreover, by adopting the fundamental crystallographic data of Professor MILLER, the symbol of the new form will be $e_{\frac{8}{3}}$, and the calculated angles, as compared with those resulting from direct measurement, are:—

	Calculated.	Observed.
$g^1\ e_{\frac{8}{3}}$	$=123^\circ\ 32'$	123° $'$ to $123^\circ\ 25'$.
$g^1\ e_{\frac{8}{3}}$ upon $e_{\frac{8}{3}}$	$=\ 56\ 28$	56 20 to 57 30.
$e_{\frac{8}{3}}\ e_{\frac{8}{3}}$ upon a^1	$=112\ 56$	113 52 mean.
${e^1}_{\frac{8}{3}}\ a^1$	$=146\ \ 8$	147 approximate.
$e_{\frac{8}{3}}\ e_{\frac{8}{3}}$ upon g^1	$=120\ 22$	121 mean.

Most of the known analyses of Wavellite indicate the presence in it of a small quantity of fluorine, sometimes as much as two per cent. M. PISANI has ascertained that the variety from Montebras, formed in the midst of other fluoriferous phosphates of alumina, contains:—

Fluorine	2·27
Phosphoric acid	34·30
Alumina	38·25
Water	26·60
	101·42
Specific gravity	2·33

XVI. THE BAKERIAN LECTURE.—*On the Radiation of Heat from the Moon, the Law of its Absorption by our Atmosphere, and of its Variation in Amount with her Phases.*

By the EARL OF ROSSE, *F.R.S.*

Received February 3,—Read March 27, 1873.

IN the years 1869 and 1870 I communicated to the Royal Society the results of a series of experiments made with the view of determining, if possible, the amount of radiant heat coming to the earth from the moon in various conditions of phase, and the nature of that heat as regards the average refrangibility of the rays. Though more successful than I had at first been led to expect, the imperfect accordance between many of the observations still left much to be desired, and the novelty and importance of the subject appeared sufficient to render it advisable to pursue the investigation with greater care and closer attention to details than had hitherto been deemed necessary.

Since the conclusion of the series of observations which form the subject of the second paper above referred to, nothing (with the exception of a short series of observations in August and October 1870, of which mention is made towards the end of this paper) was done towards pursuing the subject till the spring of the following year (1871), when the series of observations which form the subject of the present paper were commenced, the same apparatus (only slightly modified) being used and the same method of observation adopted; but, with the view of obtaining an approximate value of the absorption of the moon's heat in its passage through our atmosphere, and of rendering possible the satisfactory comparison of observations made at different zenith-distances of the moon, the observations were in many cases carried on at intervals at all possible zenith-distances on the same night, and the most favourable opportunities for observing the moon at very different zenith-distances in various conditions of the atmosphere were not lost.

Before proceeding further it may be well to mention the small changes in the apparatus already referred to.

The piles instead of being, as before, placed in two separate circuits or loops, united close to the terminals of the galvanometer, have, since the beginning of August 1870, been placed in one and the same circuit, the position of the poles of the second pile relative to the galvanometer-circuit being, as before, the reverse of the first; and further, to protect the piles more effectually from draughts of air, they and the small concave mirrors were enclosed in a box with glass* sides, that side next the large speculum being still (unless otherwise specified) left open. The piles were single pairs of small cross section of the kind described in the 'Proceedings of the Royal Society,' No. 122, 1870, and their back solderings were protected from sudden changes of temperature by being imbedded in wax. More care has been taken to protect the apparatus from the wind; and with that view, during the last two years, the cloth which had been hitherto used to cover the lattice-tube was prolonged to about 5 feet beyond the end of the tube, or 6 feet outside the piles. The three-foot telescope was employed in these as in the former experiments.

---

* Of glass to enable the assistant to see when the moon's image was central on each concave mirror.

The observations were made by directing the telescope towards the moon, so that by a slight motion the faces of the piles were alternately exposed for a period of one minute to the radiation from the part of the sky containing the moon's disk, while the other pile was exposed to that from an adjacent circle of sky. The galvanometer was read off just before each motion of the telescope. Thus the difference between two successive readings of the galvanometer exhibited the heat-effect on double the scale that would have been possible with one pile. After three or four preliminary settings of the telescope had been made, to give the assurance that every thing was in working order and the needle of the galvanometer vibrating in equal arcs on each side of the zero, eleven readings of the galvanometer, giving ten differences, were taken in succession. The sidereal time was noted and the altitude read off on a quadrant attached to the telescope, graduated to half degrees, and allowing the estimation of tenths. As far as was at all compatible with the progress of the observations all cloud was avoided, and no readings were taken unless the sky near the moon was clear or very nearly so. The zenith-distance for the middle of each set of ten differences was obtained by a graphical process from the altitudes actually observed, and the arithmetical mean (G) of the differences was taken as the corresponding heat-effect.

These quantities, and others of which an explanation is given further on, are entered in the following Table.

Journal of Observations and preliminary Reductions.

We have:—

In column III. the observed deviation of the needle.

In column IV. the moon's distance from the point directly opposite to the sun.

In column VII. the logarithm of the factor for reducing the galvanometer-readings from *tangent* to *arc*, it being assumed that the latter was proportional to the heating-effect.

In columns VIII. & IX. the respective logarithms for reducing each set of readings for change of phase and of the moon's apparent semidiameter to what it would have been had the observation been made at the time and under the circumstances given in columns XI., XII., & XIII.; so that we obtained the heating-effects (given in column X.) of the moon at various zenith-distances on each night, independent of all other causes of variation.

The remaining columns require no explanation, beyond what will be found in the pages which follow the Table.

TABLE.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.
			The Moon's							The adopted mean		
1871.	Sidereal time.	G.	ε.	Apparent zenith-distance.	Apparent semi-diameter.	log (*g*).	log (ε).	log (σ).	log (G corr.).	Sidereal time.	ε.	Apparent semi-diameter.
	h m		° ′	°	′ ″					h m	° ′	′ ″
Mar. 2.	12 22	92·9	− 50 4	61·4	15 19·8	9·9998	0·0027	9·9982	1·9687	13 20·0	− 49 36	15 18·0
*	13 12	86·2	− 49 41	68·7	15 18·1	9·9999	0·0005	0·0000	1·9359			
	13 43	72·9	− 49 26	73·0	15 17·1	9·9999	9·9990	0·0008	1·8624			
	14 8	65·4	− 49 14	76·6	15 16·1	9·9999	9·9981	0·0018	1·8151			
Mar. 27.	7 45	34·2	−106 8	42·5	14 59·5	0·0000	0·0127	9·9966	1·5433	10 0·0	−105 19	14 56·0
	8 8	36·9	−106 0	45·3	14 59·1	0·0000	0·0106	9·9970	1·5746			
	8 30	33·3	−105 53	47·8	14 58·6	0·0000	0·0089	9·9974	1·5287			
	8 58	31·5	−105 43	51·7	14 57·9	0·0000	0·0063	9·9982	1·5028			
	9 24	31·3	−105 33	55·1	14 57·2	0·0000	0·0031	9·9988	1·4974			
	10 12	25·8	−105 14	62·2	14 55·7	0·0000	9·9988	0·0004	1·4108			
	10 34	23·3	−105 4	65·3	14 55·0	0·0000	9·9962	0·0010	1·3646			
	11 16	21·9	−104 46	71·4	14 53·6	0·0000	9·9917	0·0022	1·3343			
	11 37	20 9	−104 37	74·4	14 52·9	0·0000	9·9895	0·0030	1·3126			
	11 59	17·6	−104 25	77·5	14 52·2	0·0000	9·9865	0·0036	1·2356			
Mar. 28.	8 57	40·8	− 94 46	43·3	15 4·4	0·0000	0·0097	9·9966	1·6170	11 0·0	− 94 0	15 1·0
	9 17	40·8	− 94 38	46·1	15 3·9	0·0000	0·0080	9·9972	1·6159			
	10 55	42·1	− 94 2	59·9	15 1·1	0·0000	0·0001	0·0000	1·6247			
	11 13	39·7	− 93 55	62·5	15 0·6	0·0000	9·9990	0·0004	1·5982			
	11 30	34·8	− 93 47	64·9	15 0·0	0·0000	9·9973	0·0010	1·5399			
	11 48	35·2	− 93 40	67·6	14 59·5	0·0000	9·9958	0·0014	1·5437			
	12 26	32·9	− 93 22	73·0	14 58·1	0 0000	9·9920	0·0028	1·5120			
	12 42	34·6	− 93 14	75·2	14 57·7	0·0000	9·9903	0·0032	1·5326			
Mar. 29.	9 16	66·0	− 83 30	39·0	15 13·2	9·9999	0·0101	9·9962	1·8257	11 46·0	− 82 33	15 9·2
	9 35	65·9	− 83 23	41·4	15 12·8	9·9999	0·0088	9·9966	1·8242			
	9 52	64·4	− 83 18	43·5	15 12·4	9·9999	0·0080	9·9970	1·8138			
	11 44	56·3	− 82 34	58·9	15 9·4	9·9999	0·0002	9·9998	1·7504			
	12 3	55·0	− 82 26	61·8	15 8·7	9·9999	9·9988	0·0006	1·7397			
	12 27	56·1	− 82 15	65·2	15 8·0	9·9999	9·9968	0·0012	1·7469			
	12 43	56·1	− 82 8	67·5	15 7·4	9·9999	9·9956	0·0018	1·7462			
	13 5	46·6	− 81 58	70·7	15 6·6	9·9999	9·9938	0·0026	1·6647			
	13 31	39·8	− 81 46	74·3	15 5·8	9·9999	9·9917	0·0034	1·5949			
	13 49	34·2	− 81 37	76·8	15 5·2	9·9999	9·9901	0·0040	1·5280			
Apr. 3.	10 53	315·5	− 22 49	46·6	16 18·1	9·9983	0·0034	9·9970	2·4977	14 0·0	− 21 31	16 14·4
†	11 27	318·7	− 22 35	46·0	16 18·2	9·9982	0·0028	9·9968	2·5012			
	12 8	327·5	− 22 18	46·4	16 18·1	9·9981	0·0021	9·9970	2·5124			
	12 47	318·2	− 22 3	48·2	16 17·5	9·9982	0·0014	9·9974	2·4997			
	13 55	303·2	− 21 35	53·9	16 16·4	9·9984	0·0001	9·9984	2·4786			
	15 3	315·5	− 21 2	62·1	16 14·4	9·9983	9·9987	0·0000	2·4960			
	15 44	251·7	− 20 41	67·5	16 13·0	9·9989	9·9978	0·0014	2·3990			
	(16 30	166·4)	haze									
	16 45	181·9	− 20 11	75·8	16 10·7	9·9994	9·9965	0·0034	2·2591			
Apr. 30.	12 14	204·3	− 54 42	45·1	16 4·9	9·9993	0·0060	9·9960	2·3115	14 30·0	− 53 46	16 0·5
	12 52	212·1	− 54 28	47·8	16 4·1	9·9992	0·0042	9·9968	2·3267			
	13 55	197·9	− 54 1	54·2	16 2·8	9·9993	0·0015	9·9978	2·2951			
	15 32	165·3	− 53 17	67·1	15 59·6	9·9995	9·9969	0·0008	2·2155			
	16 16	148·2	− 52 55	73·4	15 57·9	9·9996	9·9946	0·0024	2·1675			
	16 56	138·6	− 52 35	78·8	15 56·4	9·9997	9·9925	0·0036	2·1376			
May 3.	11 47	298·2	− 14 49	66·3	16 40·1	9·9984	0·0010	0·0004	2·4743	13 0·0	− 14 16	16 40·6
	12 48	324·6	− 14 21	62·3	16 41·2	9·9982	0·0002	9·9995	2·5092			

---

* On March 24th, 1871, the moon was observed at an altitude of 18°; no trace of heat was perceptible. Moon's age 3·6 days, 138° from full.

† Observations were also made on April 6 and April 7, 1871; but as they were intentionally made under most unfavourable circumstances to test the effect of wind and haze, they are not included in the above journal.

TABLE (continued).

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.
			The Moon's							The adopted mean		
1871.	Sidereal time.	G.	ε.	Apparent zenith-distance.	Apparent semi-diameter.	log (g).	log (ε).	log (σ).	log (G corr.).	Sidereal time.	ε.	Apparent semi-diameter.
	h m									h m		
May 28.	14 50	88·0	−72° 48′	59°·8	15′ 57″·9	9·9999	0·0050	9·9974	1·9468	16 0·0	−72° 14′	15′ 55″·3
	15 32	80·7	−72 29	65·2	15 56·6	9·9999	0·0025	9·9986	1·9079			
	16 7	75·5	−72 11	70·1	15 55·3	9·9999	9·9995	0·0000	1·8773			
	16 40	59·1	−71 55	74·9	15 54·0	9·9999	9·9972	0·0012	1·7699			
	16 58	51·4	−71 46	77·7	15 53·2	0·0000	9·9959	0·0018	1·7087			
	17 12	47·1	−71 39	79·6	15 52·7	0·0000	9·9949	0·0024	1·6703			
May 29.	14 26	121·4	−60 37	57·0	16 13·6	9·9997	0·0050	9·9972	2·0861	16 0·0	−59 55	16 10·7
	15 0	120·9	−60 22	60·2	16 12·8	9·9997	0·0032	9·9980	2·0834			
	15 35	106·4	−60 11	64·1	16 11·8	9·9998	0·0019	9·9990	2·0277			
	17 25	61·2	−59 14	78·5	16 7·8	9·9999	9·9951	0·0026	1·7844			
May 30.	16 22	138·3	−45 57	68·3	16 26·9	9·9997	0·0018	9·9988	2·1412	17 0·0	−45 37	16 25·7
	17 30	108·5	−45 24	76·6	16 24·5	9·9998	9·9988	0·0010	2·0351			
June 1.	15 56	279·1	−18 10	69·7	16 48·0	9·9986	0·0014	9·9988	2·4446	17 30·0	−17 29	16 46·5
	16 34	273·7	−17 53	71·0	16 47·7	9·9987	0·0008	9·9994	2·4362			
	17 13	257·2	−17 36	73·3	16 47·0	9·9988	0·0003	9·9996	2·4088			
	18 25	193·2	−17 4	79·4	16 45·1	9·9993	9·9991	0·0012	2·2856			
June 2.	15 47	327·9	− 3 59	74·3	16 50·5	9·9981	0·0001	0·0000	2·5139	16 25·0	− 3 42	16 50·5
*	16 25	285·1	− 3 42	73·8	16 50·6	9·9986	0·0000	9·9999	2·4535			
	17 2	332·5	− 3 26	74·2	16 50·5	9·9981	9·9999	0·0000	2·5197			
Nov. 1.	1 52	139·3	+51 48	55·3	14 54·0	9·9997	9·9986	0·0012	2·1435	2 30·0	+52 2	14 55·3
	2 8	130·9	+51 54	52·8	14 54·5	9·9997	9·9992	0·0008	2·1167			
	2 29	141·3	+52 2	49·9	14 55·1	9·9996	0·0000	0·0002	2·1499			
	3 31	152·2	+52 24	41·5	14 56·6	9·9996	0·0023	9·9986	2·1829			
Dec. 19.	2 21	87·4	−78 26	57·8	15 30·8	9·9999	0·0010	9·9996	1·9420	2 36·0	−78 20	15 30·4
	2 37	81·8	−78 20	59·6	15 30·3	9·9999	0·0000	0·0002	1·9129			
	2 51	79·9	−78 14	60·7	15 30·1	9·9999	9·9990	0·0004	1·9018			
Dec. 20.	1 5	121·9	−67 9	49·9	15 20·6	9·9997	0·0082	9·9970	2·0910	4 0·0	−66 8	15 17·4
	1 36	123·8	−66 58	49·5	15 20·7	9·9997	0·0067	9·9970	2·0961			
	1 51	132·3	−66 53	49·7	15 20·6	9·9997	0·0061	9·9970	2·1244			
	2 6	124·0	−66 48	50·0	15 20·6	9·9997	0·0054	9·9970	2·0955			
	5 31	103·5	−65 32	68·5	15 16·5	9·9998	9·9953	0·0010	2·0111			
	6 25	88·4	−65 9	75·8	15 14·7	9·9999	9·9922	0·0028	1·9414			
	6 39	80·5	−65 3	77·8	15 14·2	9·9999	9·9914	0·0032	1·9003			
Dec. 25.	2 8	356·1	−10 56	48·3	14 53·5	9·9978	0·0009	0·0014	2·5516	4 0·0	−10 16	14 55·0
	2 40	359·7	−10 44	44·0	14 54·2	9·9977	0·0007	0·0008	2·5552			
	3 14	357·3	−10 32	39·8	14 54·9	9·9978	0·0003	0·0000	2·5512			
	3 47	370·1	−10 20	36·1	14 55·5	9·9976	0·0001	9·9996	2·5656			
	4 26	387·6	−10 8	32·7	14 56·0	9·9974	9·9999	9·9990	2·5847			
	5 2	379·7	− 9 57	30·7	14 56·2	9·9975	9·9996	9·9988	2·5753			
	5 17	384·6	− 9 53	30·0	14 56·3	9·9974	9·9995	9·9988	2·5807			
Dec. 26.	1 57	315·4	± 0 36	56·2	14 51·4	9·9983	0·0000	0·0016	2·4988	3 0·0	+ 0 45	14 53·0
†	2 36	308·0	∓ 0 41	47·8	14 52·9	9·9983	0·0000	0·0000	2·4869			
	6 50	362·0	+ 1 22	29·3	14 55·8	9·9977	0·0001	9·9974	2·5539			

* 1871, June 2.—Full moon; the moon passed clear of the earth's shadow and penumbra.

† 1871, December 26.—Full moon; using the formula given at p. 135 of the Appendix to the Nautical Almanac for 1836, which makes the semidiameter of the earth's penumbra equal to $\frac{61}{60}(P'+\pi-\sigma)+2\sigma$ (where P′ is the moon's horizontal parallax, π the sun's parallax, and σ the sun's semidiameter), it will be found that at $3^h\ 7^m$ sidereal time the semidiameter of the penumbra was 1° 11′ 2″, while the distance of the centre of the moon from the centre of the shadow was 1° 10′ 42″; so that an immersion to the extent of 20″ only took place, but at the time of observation the moon was clear of the penumbra.

TABLE (continued).

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.
1871.	Sidereal time.	G.	The Moon's			log (g).	log (ε).	log (σ).	log (G corr.).	The adopted mean		
			ε.	Apparent zenith-distance.	Apparent semi-diameter.					Sidereal time.	ε.	Apparent semi-diameter.
	h m		° ′	°	′ ″					h m	° ′	′ ″
Dec. 28.	4 36	306·6	+ 22 49	49·9	14 56·2	9·9984	9·9977	0·0018	2·4845	7 0·0	+ 23 38	14 58·0
	5 9	297·3	+ 23 1	45·4	14 56·9	9·9984	9·9982	0·0010	2·4708			
	5 50	299·7	+ 23 16	40·3	14 57·7	9·9984	9·9989	0·0004	2·4744			
	6 19	298·7	+ 23 25	37·2	14 58·1	9·9984	9·9993	0·0000	2·4729			
	8 52	288·7	+ 24 12	31·1	14 59·0	9·9985	0·0016	9·9990	2·4596			
	9 26	274·7	+ 24 24	33·3	14 58·7	9·9987	0·0022	9·9992	2·4390			
	10 3	274·3	+ 24 37	36·5	14 58·3	9·9987	0·0028	9·9998	2·4396			
1872.												
Jan. 2.	12 39	93·8	+ 82 26	51·0	15 37·5	9·9998	9·9993	0·0000	1·9713	12 50·0	+ 82 30	15 37·5
	12 50	85·2	+ 82 30	51·2	15 37·5	9·9999	0·0000	0·0000	1·9303			
Jan. 5.	14 16	17·7	+119 46	68·2	16 17·8	0·0000	9·9984	0·0000	1·2464	14 32·0	+119 51	16 17·8
	14 32	18·5	+119 51	67·9	16 17·8	0·0000	0·0000	0·0000	1·2672			
Jan. 18.	4 29	102·7	− 74 43	45·4	15 11·8	9·9998	0·0049	9·9982	2·0145	6 0·0	− 74 11	15 10·0
*	4 45	103·1	− 74 37	46·8	15 11·5	9·9998	0·0040	9·9986	2·0156			
*	4 58	98·8	− 74 33	48·0	15 11·3	9·9998	0·0034	9·9988	1·9968			
	5 57	99·0	− 74 12	54·7	15 10·0	9·9998	0·0002	0·0000	1·9956			
	6 12	95·9	− 74 6	56·6	15 9·6	9·9998	9·9993	0·0002	1·9811			
*	6 24	90·0	− 74 2	58·2	15 9·3	9·9999	9·9980	0·0006	1·9527			
	7 36	86·7	− 73 34	68·2	15 7·0	9·9999	9·9943	0·0028	1·9350			
Jan. 19.	5 34	136·8	− 63 10	42·9	15 4·5	9·9997	0·0003	0·0000	2·1361	5 42·0	− 63 7·5	15 4·4
	5 50	125·6	− 63 5	44·6	15 4·2	9·9997	9·9996	0·0002	2·0985			
Jan. 20.	8 57	185·5	− 50 59	59·8	14 55·1	9·9994	0·0003	9·9998	2·2677	9 5·0	− 50 56	14 54·9
†	9 13	175·6	− 50 53	62·0	14 54·7	9·9995	9·9997	0·0002	2·2438			
Jan. 22.	9 55	163·6	− 28 54	50·1	14 53·4	9·9995	0·0006	9·9992	2·2131	10 20·0	− 28 44	14 52·7
	10 23	176·6	− 28 43	54·2	14 52·7	9·9995	9·9999	0·0000	2·2464			
	10 40	188·4	− 28 37	57·2	14 52·0	9·9994	9·9996	0·0006	2·2747			
Jan. 27.	5 16	247·6	+ 25 19	70·4	15 16·1	9·9989	....	....	2·3927	5 16·0	+ 25 19	15 16·1
Jan. 30.	9 17	116·4	+ 61 40	69·8	15 32·2	9·9998	9·9985	0·0010	2·0653	9 48·0	+ 61 53	15 33·2
	9 32	128·1	+ 61 46	68·0	15 32·7	9·9997	9·9992	0·0006	2·1070			
	9 47	130·0	+ 61 53	66·3	15 33·1	9·9997	0·0000	0·0002	2·1138			
‡	10 1	118·3	+ 61 58	64·8	15 33·5	9·9997	0·0007	9·9998	2·0732			
	10 16	130·4	+ 62 4	63·3	15 33·9	9·9997	0·0014	9·9994	2·1157			
‡	10 27	130·1	+ 62 9	62·2	15 34·1	9·9997	0·0020	9·9994	2·1153			
Feb. 1.	14 12	70·7	+ 87 54	66·1	15 57·7	9·9999	....	....	1·8493	14 12·0	+ 87 54·0	15 57·7
Feb. 16.	5 53	88·1	− 83 46	39·4	15 6·5	9·9999	0·0063	9·9974	1·9486	7 30·0	− 83 12	15 3·5
	6 14	80·2	− 83 39	41·7	15 6·1	9·9999	0·0051	9·9976	1·9068			
	6 27	75·2	− 83 35	43·1	15 5·9	9·9999	0·0043	9·9976	1·8780			
	6 43	77·1	− 83 29	45·0	15 5·5	9·9999	0·0033	9·9982	1·8885			
	9 15	65·8	− 82 32	65·7	15 1·2	9·9999	9·9931	0·0022	1·8134			
	9 28	62·2	− 82 26	67·5	15 0·8	9·9999	9·9920	0·0026	1·7884			
Feb. 20.	12 33	197·6	− 38 21	60·7	14 55·6	9·9993	0·0009	9·9994	2·2954	13 0·0	− 38 9	14 55·0
	12 47	183·1	− 38 15	62·7	14 55·3	9·9994	0·0004	9·9998	2·2623			
	13 0	174·7	− 38 9	64·5	14 54·9	9·9995	0·0000	0·0002	2·2419			
	13 14	171·7	− 38 2	66·4	14 54·4	9·9995	9·9995	0·0006	2·2343			

* 1872, January 18.—On this night an iron candle-holder stood near the galvanometer; experiments made March 13 show, however, that it did not affect the value of the readings although it considerably altered the zero. The sets at 4h 58m and 6h 24m consisted only of eight and five differences respectively; but as these were made under favourable circumstances, full weight has been given to them.

† January 20.—The scale was 36·5 in. from the mirror of the galvanometer instead of at the usual distance of 36·0 in.; therefore the readings have been multiplied by $\frac{36·0}{36·5}$.

‡ January 30.—10h 1m, barely perceptible haze 10h 27m, very light cloud again.

TABLE (continued).

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.
			The Moon's							The adopted mean		
1872.	Sidereal time.	G.	ε.	Apparent zenith-distance.	Apparent semi-diameter.	log (g).	log (ε).	log (σ).	log (G corr.).	Sidereal time.	ε.	Apparent semi-diameter.
	h m		° ′	°	′ ″					h m	° ′	′ ″
Feb. 24.	9 19	347·5	+ 7 57	46·7	15 22·0	9·9979	9·9993	0·0000	2·5381	11 30·0	+ 8 33	15 22·0
	9 34	341·5	+ 8 0	45·5	15 22·2	9·9980	9·9994	9·9998	2·5306			
	10 10	334·0	+ 8 11	43·4	15 22·5	9·9980	9·9996	9·9996	2 5209			
	11 34	314·5	+ 8 33	42·8	15 22·7	9·9983	0·0000	9·9994	2·4953			
	11 48	313·7	+ 8 38	43·3	15 22·6	9·9983	0·0001	9·9996	2·4945			
	12 2	315 8	+ 8 42	44·0	15 22·5	9·9983	0·0002	9·9996	2·4975			
	12 16	306·2	+ 8 46	44·8	15 22·4	9·9981	0·0002	9·9996	2·4842			
	12 53	274·4	+ 8 58	47·7	15 21·8	9·9987	0·0005	0·0000	2·4376			
Mar. 21.	10 11	298·9	− 36 56	36·3	15 15·4	9·9984	0·0010	9·9996	2·4746	10 45·0	−36 42	15 15·1
	10 44	296·7	− 36 42	37·4	15 15·2	9·9985	0·0000	9·9998	2·4706			
	11 22	282·1	− 36 29	39·8	15 14·8	9·9986	9·9992	0·0002	2·4484			
Mar. 22.	11 57	290·0	− 24 50	42·9	15 23·7	9·9985	0·0011	9·9992	2·4612	13 0·0	−24 27	15 22·8
	12 11	285·5	− 24 46	44·1	15 23·5	9·9986	0·0009	9·9994	2·4545			
	12 25	290·3	− 24 40	45·3	15 23·4	9·9985	0·0006	9·9994	2·4613			
	12 57	278·2	− 24 28	48·2	15 22·7	9·9986	0 0000	0·0002	2·4431			
	13 48	265·5	− 24 8	54·3	15 22·3	9·9988	9·9990	0·0012	2·4230			
	14 4	258·6	− 24 0	56·3	15 21·0	9·9988	9·9986	0·0016	2·4116			
Mar. 24.	9 48	354·3	− 4 26	59·3	15 39·3	9·9978	0·0001	0·0006	2·5479	12 0·0	− 4 9	15 40·0
*	11 47	361·8	− 4 10	51·5	15 41·0	9·9977	0·0000	9·9990	2·5552			
	13 37	364·1	− 4 1	53·5	15 40·6	9·9977	9·9999	9·9994	2·5582			
	13 51	363·5	− 4 0	54·5	15 40·4	9·9977	9·9999	9·9996	2·5577			
	14 21	358·5	− 4 0	56·9	15 39·9	9·9977	9·9999	0·0000	2·5521			
Mar. 26.	11 52	251·3	+ 24 44	68·1	15 54·6	9·9989	....	....	2·3991	11 52·0	+24 44	15 54·6
Apr. 15.	12 21	57·7	− 89 53	57·1	14 56·9	9·9999	0·0012	9·9996	1·7619	12 36·0	−89 47	14 56·4
	12 36	50·4	− 89 47	59·3	14 56·4	0·0000	0·0000	0·0000	1·7024			
	12 50	52·4	− 89 41	61·4	14 56·0	0·0000	9·9988	0·0004	1·7185			
Apr. 18.	10 57	175·1	− 56 55	38·8	15 19·1	9·9995	0·0050	9·9972	2·2449	13 0·0	−56 11	15 16·0
	11 53	166·1	− 56 35	42·2	15 18·6	9·9995	0·0027	9·9976	2·2202			
	12 26	161·4	− 56 24	45·3	15 18·1	9·9995	0·0015	9·9982	2·2071			
	12 41	164·2	− 56 18	46·8	15 17·7	9·9995	0·0013	9·9984	2·2145			
	13 57	159·7	− 55 48	56·3	15 15·8	9·9996	9·9975	0 0002	2·2007			
	14 11	154·1	− 55 42	58·3	15 15·4	9·9996	9·9968	0·0006	2·1848			
	14 25	156·9	− 55 37	60·3	15 14·9	9·9996	9·9963	0·0012	2·1927			
	14 53	147·1	− 55 24	64·4	15 14·0	9·9996	9·9948	0·0020	2·1640			
	15 9	129·8	− 55 17	66·7	15 13·4	9·9997	9·9941	0·0024	2·1096			

Determination of the Law of Extinction of the Moon's Radiant Heat in our Atmosphere.

As, apart from any *à priori* consideration, an examination of the former observations had shown that the quantity of heat reaching us from the moon was dependent upon her zenith-distance, it was necessary that the whole of the new observations should be carefully examined in order to determine the law of this dependence. But since the moon's phase and distance from the place of observation and from the sun's centre are constantly changing, the observations had to be freed from the first two of these sources of change before they could be used for deducing the corrections dependent upon the zenith-distance.

The necessary elements for the corrections were obtained as follows. The moon's

* March 24.—The sky rather hazy all night, but the observations were only taken during the clearer intervals.

tabular place was taken from the Nautical Almanac for every hour of sidereal time over which the observations extended; then the moon's parallax was calculated, also for every hour, by the following approximate formulæ*:—

$$\left.\begin{aligned} \alpha'-\alpha &= -[0\cdot3815]\,\mathrm{P}\sin(\Theta-\alpha)\sec\delta \\ \tan\gamma &= \frac{[0\cdot1215]}{\cos(\Theta-\alpha)}, \\ \delta'-\delta &= -\frac{[9\cdot9009]\sin(\gamma-\delta)}{\sin\gamma}\,\mathrm{P}, \end{aligned}\right\}$$

where $\alpha'=$ moon's apparent right ascension,

$\alpha =$ moon's true right ascension,

$\delta' =$ moon's apparent declination,

$\delta =$ moon's true declination,

$\mathrm{P}=$ moon's equatorial horizontal parallax,

$\Theta=$ sidereal time,

and $[0\cdot3815]=\log\frac{\rho'\cos\phi'}{15}$,

$[0\cdot1215]=\log\tan\phi'$,

$[9\cdot9009]=\log\rho'\sin\phi'$,

where $\rho'=$ distance from centre of the earth,

$\phi'=$ geocentric latitude.

From the apparent places so obtained the moon's apparent elongation (ϵ) from the point opposite the sun was derived by the equation

$$\cos(\pi-\epsilon)=\sin\mathrm{D}\sin\delta'+\cos\mathrm{D}\cos\delta'\cos(\mathrm{A}-\alpha'),$$

where

$\mathrm{D}=$ sun's declination,

$\mathrm{A}=$ sun's right ascension.

It is evident that $\pi-\epsilon$ represents very nearly the angular amount of the moon's apparent illuminated phase. A slight inaccuracy arises from neglecting the angle at the sun† in the plane triangle earth, sun, moon.

The moon's tabular semidiameter and a Table of augmentations gave her apparent semidiameter, σ. Finally, the moon's apparent altitude was taken from a Table of double entry calculated for the latitude of Birr Castle, to test, by its agreement with the readings of the quadrant, the accuracy of the calculations mentioned above.

In the absence of an exact knowledge of the law of variation of the moon's radiant heat with her change of phase, that enunciated at page 439, No. 112 of the 'Proceedings of the Royal Society,' 1869, was adopted*. In accordance with this law, if the radiant heat of the full moon be represented by unity, the heat (h) at any other phase will be (*cœteris paribus*)

---

* Brünnow's 'Spherical Astronomy,' page 150 (English edition, 1865).

† This angle never exceeds 9′ even at quadrature.

$$h=\frac{(\pi-\varepsilon)\cos\varepsilon+\sin\varepsilon}{\pi}.$$

The logarithmic factors for reducing observations made at any elongation to a mean value (ε_0) for the night were readily derived from a Table of log h for every degree of ε.

As the moon's heating-power doubtless varies (*cœteris paribus*) as the square of her apparent semidiameter, the double of the logarithm of the apparent semidiameter at different times affords the simplest form of reduction for change of distance. In this way the logarithmic factors for correcting for changes of ε and σ in columns log (ε) and log (σ) were obtained.

For the larger readings of the galvanometer there is a small correction required to reduce the readings from tangent to arc†. This correction may be conveniently brought into the form of a factor if we assume, as was approximately the case, especially for the larger readings, that the amplitudes were equally large on each side of the zero-point‡. For if n is the difference of two readings and r the distance of the scale from the galvanometer, the correcting factor will be $\left(1-\frac{1}{12}\frac{n^2}{r^2}\right)$. In our case $r=1440$, and the log factor becomes

$$\text{log corr. }(g)=\log\left(1-\frac{n^2}{24883200}\right).$$

The values of log corr. (g) are given in column log (g) for each observation.

The sum of log G, log (g), log (ε), and log (σ) gives column log (G corr.), the logarithm

---

* There is a misprint in formula (a) at the place referred to; it should have been

$$Q=100\left[\left(1-\frac{\epsilon}{\pi}\right)\cos\epsilon+\frac{\sin\epsilon}{\pi}\right].$$

Since the publication of that paper it has been found that LAMBERT, in his 'Photometria,' had already made use of it in the form $c=\frac{2(\sin v-v\,.\cos v)\,.\,A\,.\sin^2 s\,.\sin^2\sigma\,.\,C}{3\pi\,.\sin^2 S}$,

where A=mean "albedo" of moon's surface,

s =sun's apparent semidiameter as seen at the moon,

σ =moon's apparent semidiameter,

C=brightness of an absolutely white plane illuminated by perpendicularly incident rays of the sun,

c =brightness of an absolutely white plane similarly illuminated by the rays of the moon,

v =elongation from the sun=180°$-\epsilon$,

S=sun's semidiameter as seen from the earth.

† It appears rather doubtful whether this small correction (which only amounts at most to $\frac{1}{200}$ of the whole heating-effect) should have been made at all, as from subsequent experiment the deviations in different parts of the scale were found to be very nearly identical with the same heating-effect; in fact the difference was less than the probable error of observation.

‡ Strictly speaking this correction should have been applied to each single reading, not to the mean of a set of readings, as was done to save labour.

of G corrected for change of phase, change of distance, and for the variation of the values of the scale.

These corrected values of log G are now available for the determination of the law of the extinction of the moon's radiant heat in the earth's atmosphere. For this purpose a graphic method, suggested by that employed by SEIDEL* in his researches concerning the extinction of stellar light, was made use of. The night's observations were arranged in order of zenith-distance, then from the log (G corr.) corresponding to the least zenith-distance on any given night each other log (G corr.) of that night was subtracted. The logarithmic differences so obtained were then entered on a sheet of cross-lined paper as ordinates, the zenith-distances being taken as abscissæ; a curve drawn through these points gave what might be called the reducing curve in zenith-distance for that night. A second night's observations were then treated in the same way, and the resulting curve moved up or down until it intersected the first night's curve at the middle of their overlapping parts. A third curve corresponding to a third night was then drawn and made to agree as nearly as possible with the mean of the curves already laid down; in this way thirty-three curves representing the logarithmic differences of the moon's radiant heat at different zenith-distances were laid down.

The mean of the differences in each degree of zenith-distance was now entered as a point at its corresponding mean zenith-distance on a separate sheet of paper, the number of observations being indicated by short radiating lines, in the way often adopted for star magnitudes, a simple dot representing a single observation. The ordinates of a curve drawn through or near these points gave a provisional Table for ϕz, or the logarithm that must be added to that of the reading at any zenith-distance to obtain the logarithm of the reading as it would have been shown had the moon been in the zenith. The Table thus deduced for the extinction of the moon's heat is here given in an abbreviated form.

Zen.-dist.	ϕz.
29°	0·0070
30	0·0071
35	0·0089
40	0·0124
45	0·0189
50	0·0296
55	0·0447
60	0·0665
65	0·1025
70	0·1525
75	0·2200
79	0·3079

---

* 'Untersuchungen über die gegenseitige Helligkeit der Fixsterne erster Grösse und über die Extinction des Lichtes in der Atmosphäre. Nebst einem Anhange über die Helligkeit der Sonne verglichen mit Sternen, und über die Licht reflectirende Kraft der Planeten.' Von LUDWIG SEIDEL. Munich, 1852.

As the moon was not observed at a less zenith-distance than 29°, SEIDEL'S value of φz for 29° was adopted: it is almost needless to remark that all the observations might equally well have been reduced to 29° zenith-distance as a superior limit; the only effect would have been to lessen all the subsequent numbers of this paper by $\frac{1}{60}$ part. With the help of the above Table all the observations were reduced to the zenith, and a mean zenith value for each night obtained. From these mean zenith quantities the mean values corresponding to the altitudes at which observations had been taken were calculated, and logarithmic differences formed exactly as had been done with the observations. These differences were now compared with those derived from observation, and from them was drawn the following list of the outstanding errors (C−O), expressed in units of the fourth place of decimals, where the sign + represents a greater absorption of radiant heat in the lower regions of the atmosphere at the time of observation than under average circumstances.

Comparison of observations with reducing curve in zenith-distance.

1871.	Zenith-distances.		C−O.
Mar. 2.	61°·4	68°·7	−304
	,,	73·0	−80
	,,	76·6	−218
Mar. 27.	42·5	45·3	−355
	,,	47·8	+56
	,,	51·7	+213
	,,	55·1	+260
	,,	62·2	+673
	,,	65·3	+887
	,,	71·4	+552
	,,	74·4	+359
	,,	77·5	+530
Mar. 28.	43·3	46·1	−34
	,,	59·9	−573
	,,	62·5	−474
	,,	64·9	−83
	,,	67·6	−373
	,,	73·0	−682
	,,	75·2	−1228
Mar. 29.	39·0	41·4	−12
	,,	43·5	+65
	,,	58·9	+259
	,,	61·8	+195
	,,	65·2	−143
	,,	67·5	−352
	,,	70·7	+116
	,,	74·3	+334
	,,	76·8	+543
Apr. 3.	46·0	46·4	−121
	,,	46·6	+24
	,,	48·2	−31
	,,	53·9	+22
	,,	62·1	−539
	,,	67·5	−31
	,,	75·8	+286
Apr. 30.	45°·1	47°·8	−210
	,,	54·2	−79
	,,	67·1	−97
	,,	73·4	−356
	,,	78·8	−1137
May 3.	62·3	66·3	+18
May 28.	59·8	65·2	+1
	,,	70·1	−178
	,,	74·9	+240
	,,	77·7	+291
	,,	79·6	+173
May 29.	57·0	60·2	−122
	,,	64·1	+167
	,,	78·5	+604
May 30.	68·3	76·6	−99
June 1.	69·7	71·0	−64
	,,	73·3	−85
	,,	79·4	−105
June 2.	73·8	74·2	−725
	,,	74·3	−683
Nov. 1.	41·5	49·9	+275
	,,	52·8	+425
	,,	55·3	+76
Dec. 19.	57·8	59·6	−97
	,,	60·7	−50
Dec. 20.	49·5	49·7	−288
	,,	49·9	+41
	,,	50·0	−7
	,,	68·5	−301
	,,	75·8	−612
	,,	77·8	−634

TABLE (continued).

1871.	Zenith-distances.		C−O.		1872.	Zenith-distances.		C−O.	
Dec. 25.	30°·0	30°·7	+53		Feb. 16.	39°·4	41°·7	+394	
	,,	32·7		−48		,,	43·1	+665	
	,,	36·1	+128			,,	45·0	+531	
	,,	39·8	+247			,,	65·7	+383	
	,,	44·0	+154			,,	67·5	+461	
	,,	48·3	+111						
					Feb. 20.	60·7	62·7	+198	
Dec. 26.	29·3	47·8	+501			,,	64·5	+258	
	,,	56·2	+132			,,	66·4	+164	
Dec. 28.	31·1	33·3	+201		Feb. 24.	42·8	43·3	+2	
	,,	36·5	+178			,,	43·4		−266
	,,	37·2		−161		,,	44·0		−37
	,,	40·3		−201		,,	44·8	+82	
	,,	45·4		−235		,,	45·5		−394
	,,	49·9		−467		,,	46·7		−486
1872.						,,	47·7	+493	
Jan. 2.	51·0	51·2	+405						
					Mar. 21.	36·3	37·4	+32	
Jan. 5.	67·9	68·2	+177			,,	39·8	+234	
Jan. 18.	45·4	46·8		−36	Mar. 22.	42·9	44·1	+53	
	,,	48·0	+127			,,	45·3		−36
	,,	54·7		−52		,,	48·2	+88	
	,,	56·6	+23			,,	54·3	+117	
	,,	58·2	+242			,,	56·3	+163	
	,,	68·2		−339					
					Mar. 24.	51·5	53·5		−90
Jan. 19.	42·9	44·6	+449			,,	54·5		−117
						,,	56·9		−147
Jan. 20.	59·8	62·0	+103			,,	59·3		−216
Jan. 22.	50·1	54·2		−454	Apr. 15.	57·1	59·3	+493	
	,,	57·2		−846		,,	61·4	+208	
Jan. 30.	62·2	63·3	+15		Apr. 18.	38·8	42·2	+209	
	,,	64·8	+317			,,	45·3	+296	
	,,	66·3		−224		,,	46·8	+294	
	,,	68·0		−323		,,	56·3	+62	
	,,	69·8		−98		,,	58·3	+236	
						,,	60·3		−48
						,,	64·4		−52
						,,	66·7	+282	

These errors were now treated in the ingenious way employed by SEIDEL (Untersuchungen, p. 41)—a Table was formed in which the zenith-distance was the argument for both horizontal and vertical columns; the errors were now entered at both points of intersection corresponding to the pairs of altitudes to which they belong.

When the lesser zenith-distance is the argument for the vertical column, the sign given in the Table was retained, in the other case the sign was changed; in this way all the errors come to stand on one side of the diagonal as they are in the Table, and on the other side with changed signs. The vertical and horizontal columns were now examined to see whether one particular sign predominated in any part. In fact the following corrections of the values of ϕz were found to be indicated:—

Zen.-dist.		Log correction.
29°	−	0·0100
35	−	·0049
40	−	·0008
45	+	·0027
50	+	·0050
55	+	·0054
60	+	·0032
65	−	·0011
70	−	·0041
75	−	·0041
79	−	·0082

The corrected curve was then found to intersect Seidel's at 38°·2 and at 44°·0, while it was 0·0034 below it at 29°·0, and 0·0038 below it at 50°·0. On comparing the two curves for the whole interval between 29° and 50°, the new curve was found to be exactly 0·0010 below Seidel's on an average; and since, as has already been said, our observations do not extend to within less than 29° of the zenith, this correction of +0·0010 was applied to the whole of the Table deduced from the new curve. At the same time a small systematic error which had arisen from an oversight in the Table for log (g) was allowed for; the error from this source might have been neglected, as it was only 0·0001 for $z=35°·5$, increasing to 0·0004 at 78°·5. These corrections being made, and the tabular quantities being slightly adjusted so as to make the differences run more regularly, the following definite Table for the extinction of the moon's radiant heat in the atmosphere was obtained, where, as before, the argument is the true zenith-distance, and ϕz is the logarithmic factor for reducing to the zenith.

Corrected Table for reducing to the zenith.

Zen.-dist.	ϕz.		Zen.-dist.	ϕz.		Zen.-dist.	ϕz.		Zen.-dist.	ϕz.	
29°	0·0046		42°	0·0227		55°	0·0575		68°	0·1348	
30	0·0056	10	43	0·0247	20	56	0·0609	34	69	0·1449	101
31	0·0067	11	44	0·0268	21	57	0·0645	36	70	0·1557	108
32	0·0078	11	45	0·0290	22	58	0·0683	38	71	0·1673	116
33	0·0090	12	46	0·0314	24	59	0·0725	42	72	0·1797	124
34	0·0102	12	47	0·0339	25	60	0·0771	46	73	0·1930	133
35	0·0115	13	48	0·0365	26	61	0·0823	52	74	0·2074	144
36	0·0129	14	49	0·0392	27	62	0·0881	58	75	0·2232	158
37	0·0143	14	50	0·0420	28	63	0·0945	64	76	0·2407	175
38	0·0158	15	51	0·0449	29	64	0·1014	69	77	0·2603	196
39	0·0174	16	52	0·0479	30	65	0·1088	74	78	0·2823	220
40	0·0191	17	53	0·0510	31	66	0·1167	79	79	0·3069	246
41	0·0209	18	54	0·0542	32	67	0·1254	87			
42	0·0227	18	55	0·0575	33	68	0·1348	94			

A comparison with SEIDEL's Table[*] given below at once shows that the extinction of the moon's radiant heat, although following a very similar law to that for stellar light, is not so great at considerable zenith-distances.

At 79° zenith-distance the difference is about one tenth of the whole amount[†].

On the Connexion between the Moon's Phase and the amount of her Radiant Heat.

The observations were now reduced to the zenith, and the mean zenith-values deduced from each night, each observation having a weight apportioned to it inversely proportional to the number of which ϕz is the logarithm. With the zenith-means and the extinction Table the values in column "G calc." of the following Table were calculated, and from the differences between observation and calculation the probable error of each observation and of the zenith-mean, z, was deduced by the usual formulæ. These are given in columns *p.e.* and $p.e._z$.

The probable errors are of course based on the assumption that no constant source of error existed; we shall, however, see further on that most probably large constant errors were present on many occasions.

---

[*] For the convenience of English readers we give SEIDEL's Table for the extinction of light in the atmosphere (Untersuchungen, p. 43) (for full title, see note, p. 595).

For $z < 14°$ the values of ϕz are imperceptible.

z.	ϕz.	z.	ϕz.	z.	ϕz.	z.	ϕz.		z.	ϕz.	
13°	0·000	28°	0·006	43°	0·023	58°	0·083	7	73°	0·233	16
14	0·001	29	0·007	44	0·026	59	0·090	7	74	0·249	19
15	0·001	30	0·007	45	0·028	60	0·097	7	75	0·268	20
16	0·001	31	0·008	46	0·031	61	0·104	8	76	0·288	21
17	0·001	32	0·009	47	0·034	62	0·112	9	77	0·309	24
18	0·002	33	0·010	48	0·038	63	0·121	9	78	0·333	26
19	0·003	34	0·011	49	0·041	64	0·130	10	79	0·359	29
20	0·003	35	0·012	50	0·045	65	0·140	10	80	0·388	40
21	0·003	36	0·013	51	0·049	66	0·150	10	81	0·428	56
22	0·003	37	0·014	52	0·053	67	0·160	10	82	0·484	65
23	0·004	38	0·015	53	0·057	68	0·170	10	83	0·549	67
24	0·004	39	0·016	54	0·062	69	0·180	11	84	0·616	68
25	0·005	40	0·017	55	0·067	70	0·191	13	85	0·684	70
26	0·005	41	0·019	56	0·072	71	0·204	14	86	0·754	
27	0·006	42	0·021	57	0·077	72	0·218	15			
28	0·006	43	0·023	58	0·083	73	0·233				

At p. 503 of the 'Abhandlungen der Math.-phys. Classe der K. Akademie der Wissenschaften,' Munich, 1861, Professor SEIDEL gives a new Table of ϕz based on seventeen years' observations; but it differs so little (at most 1 per cent.) from the Table here given, that Professor SEIDEL himself, for the sake of uniformity, continued to make use of the original Table only. Where the difference between the Tables for light and heat is greatest, Professor SEIDEL's new Table lessens this difference by about one seventh part.

[†] *Note added Dec.* 27, 1873.—Since writing the above, a possible way of accounting for the difference between the heat- and light-extinction curves has been found in the circumstance that the former was obtained from observations on the moon, the latter from observations on the stars. In the former case less loss would arise from bad definition at low altitudes than in the latter, as the greater part of the light and heat would be simply transferred from one part of the moon's image to another; whereas in the latter case it would be transferred from the star's image to the sky round it, when it would only tend to lessen the contrast. Consequently it does not necessarily follow that the foregoing observations point to different laws for light and heat.

Reduction of observations to the zenith.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
1871.	Zenith-distance.	Observed G corr.	G calc.	C−O.	*p.e.*	Zenith-mean (z).	*p.e.z.*
Mar. 2.	61°·4	93·1	95·1	+ 2·0	± 1·5	115·6	±1·1
	68·7	86·3	83·4	− 2·9			
	73·0	72·9	74·1	+ 1·2			
	76·6	65·4	64·6	− 0·8			
Mar. 27.	42·5	34·9	33·3	− 1·6	± 1·7	35·13	±0·68
	45·3	37·6	32·8	− 4·8			
	47·8	33·8	32·3	− 1·5			
	51·7	31·8	31·5	− 0·3			
	55·1	31·4	30·8	− 0·6			
	62·2	25·8	28·6	+ 2·8			
	65·3	23·2	27·2	+ 4·0			
	71·4	21·6	23·6	+ 2·0			
	74·4	20·5	21·5	+ 1·0			
	77·5	17·2	18·8	+ 1·6			
Mar. 28.	43·3	41·4	44·8	+ 3·4	± 2·1	47·47	±0·95
	46·1	41·3	44·1	+ 2·8			
	59·9	42·1	39·8	− 2·3			
	62·5	39·6	38·5	− 1·1			
	64·9	34·7	37·0	+ 2·3			
	67·6	35·0	35·1	+ 0·1			
	73·0	32·5	30·4	− 2·1			
	75·2	34·1	28·2	− 5·9			
Mar. 29.	39·0	67·0	66·1	− 0·9	± 1·8	68·79	±0·72
	41·4	66·7	65·4	− 1·3			
	43·5	65·1	64·8	− 0·3			
	58·9	56·3	58·3	+ 2·0			
	61·8	54·9	56·3	+ 1·4			
	65·2	55·8	53·4	− 2·4			
	67·5	55·8	51·0	− 4·8			
	70·7	46·2	47·2	+ 1·0			
	74·3	39·4	42·2	+ 2·8			
	76·8	33·7	38·2	+ 4·5			
Apr. 3.	46·6	314·6	320·5	+ 5·9	± 9·8	345·7	±4·1
*	46·0	317·1	321·6	+ 4·5			
	46·4	325·4	320·8	− 4·6			
	48·2	316·0	317·5	+ 1·5			
	53·9	301·0	305·4	+ 4·4			
	62·1	313·3	281·8	−31·5			
	67·5	250·6	256·3	+ 5·7			
	75·8	181·6	200·3	+18·7			
Apr. 30.	45·1	204·8	213·1	+ 8·3	± 7·9	228·0	±4·1
	47·8	212·2	209·9	− 2·3			
	54·2	197·2	200·9	+ 3·7			
	67·1	164·3	170·4	+ 6·1			
	73·4	147·1	144·3	− 2·8			
	78·8	137·3	113·8	−23·5			
May 3.	66·3	298·1	299·9	+ 1·8	± 1·9	395·0	±1·7
	62·3	322·9	320·8	− 2·1			

TABLE (continued).

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
1871.	Zenith-distance. °	Observed G corr.	G calc.	C—O.	$p.e.$	Zenith-mean (z).	$p.e_z.$
May 28.	59·8	88·5	86·5	− 2·0	± 2·0	103·1	± 1·2
	65·2	80·9	80·0	− 0·9			
	70·1	75·4	71·9	− 3·5			
	74·9	58·9	61·9	+ 3·0			
	77·7	51·1	54·6	+ 3·5			
	79·6	46·8	49·1	+ 2·3			
May 29.	57·0	121·9	119·3	− 2·6	± 4·5	138·4	± 3·0
	60·2	121·2	115·6	− 5·6			
	64·1	106·6	109·4	+ 2·8			
	78·5	60·9	70·3	+ 9·4			
May 30.	68·3	138·5	139·4	+ 0·9	± 1·1	191·4	± 1·1
	76·6	108·4	107·2	− 1·2			
June 1.	69·7	278·3	281·6	+ 3·3	± 1·6	400·0	± 1·3
	71·0	273·0	272·2	− 0·8			
	73·3	256·4	254·0	− 2·4			
	79·4	193·1	192·7	− 0·4			
June 2.	74·3	326·5	311·5	−15·0	±19·4	507·5	±18·1
*	73·8	284·1	317·0	+32·9			
	74·2	330·9	312·5	−18·4			
Nov. 1.	55·3	139·2	136·0	− 3·2	± 3·7	155·6	± 2·0
	52·8	130·8	138·6	+ 7·8			
	49·9	141·3	141·4	+ 0·1			
	41·5	152·4	148·0	− 4·4			
Dec. 19.	57·8	87·5	84·4	− 3·1	± 1·9	98·58	± 1·28
	59·6	81·8	82·9	+ 1·1			
	60·7	79·8	81·9	+ 2·1			
Dec. 20.	49·9	123·3	128·1	+ 4·8	± 3·2	141·0	± 1·5
	49·5	124·7	128·4	+ 3·7			
	49·7	133·1	128·2	− 4·9			
	50·0	124·6	128·0	+ 3·4			
	68·5	102·6	102·2	− 0·4			
	75·8	87·4	81·7	− 5·7			
	77·8	79·5	74·4	− 5·1			
Dec. 25.	48·3	356·1	351·4	− 4·7	± 4·3	382·9	± 1·7
	44·0	359·1	359·9	+ 0·8			
	39·8	355·8	366·6	+10·8			
	36·1	367·8	371·5	+ 3·7			
	32·7	384·3	375·3	− 9·0			
	30·7	376·1	377·2	+ 1·1			
	30·0	380·8	377·9	− 2·9			
Dec. 26.	56·2	315·4	306·3	− 9·1	±10·6	353·1	± 6·6
*	47·8	306·8	324·9	+18·1			
	29·3	358·0	349·0	− 9·0			

TABLE (continued).

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
1871.	Zenith-distance.	Observed G corr.	G calc.	C–O.	*p.e.*	Zenith-mean (z).	$p.e_z$.
Dec. 28.	49°·9	305·2	275·5	−29·7	±12·5	303·3	±5·0
	45·4	295·6	283·0	−12·6			
	40·3	298·2	289·9	− 8·3			
	37·2	297·1	293·3	− 3·8			
	31·1	288·1	298·6	+10·5			
	33·3	274·8	296·8	+22·0			
	36·5	275·2	294·0	+18·8			
1872. Jan. 2.	51·0	93·6	89·4	− 4·2	± 4·1	99·2	±3·1
	51·2	85·2	89·3	+ 4·1			
Jan. 5.	68·2	17·6	18·0	+ 0·4	± 0·4	24·67	±0·41
	67·9	18·5	18·1	− 0·4			
Jan. 18.	45·4	103·4	103·4	0·0	± 2·1	110·7	±0·9
*	46·8	103·6	102·6	− 1·0			
*	48·0	99·3	101·8	+ 2·5			
	54·7	99·0	97·2	− 1·8			
	56·6	95·7	95·8	+ 0·1			
*	58·2	89·7	94·4	+ 4·7			
	68·2	86·1	80·8	− 5·3			
Jan. 19.	42·9	136·8	131·7	− 5·1	± 4·9	139·3	±3·7
	44·6	125·4	130·6	+ 5·2			
Jan. 20.	59·8	185·2	182·7	− 2·5	± 2·5	217·8	±2·0
	62·0	175·3	177·8	+ 2·5			
Jan. 22.	50·1	163·3	180·5	+17·2	±11·5	199·0	±7·5
	54·2	176·4	175·4	− 1·0			
	57·2	188·2	171·2	−17·0			
Jan. 27.	70·4	247·0	……	……	……	357·2	
Jan. 30.	69·8	116·2	115·1	− 1·1	± 4·2	163·9	±2·2
	68·0	127·9	120·1	− 7·8			
	66·3	129·9	124·6	− 5·3			
*	64·8	118·4	128·0	+ 9·6			
	63·3	130·5	131·2	+ 0·7			
*	62·2	130·4	133·5	+ 3·1			
Feb. 1.	66·1	70·7	……	……	……	92·6	
Feb. 16.	39·4	88·8	81·3	− 7·5	± 2·8	84·8	±1·3
	41·7	80·7	80·6	− 0·1			
	43·1	75·5	80·1	+ 4·6			
	45·0	77·4	79·3	+ 1·9			
	65·7	65·1	65·2	+ 0·1			
	67·5	61·4	62·8	+ 1·4			
Feb. 20.	60·7	197·4	189·8	− 7·6	± 3·6	228·4	±2·3
	62·7	182·9	184·6	+ 1·7			
	64·5	174·6	179·4	+ 4·8			
	66·4	171·5	173·3	+ 1·8			

TABLE (continued).

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
1872.	Zenith-distance.	Observed G corr.	G calc.	C−O.	p.e.	Zenith-mean (z).	p.e_z.
Feb. 24.	46°·7	345·2	313·5	−31·7	±14·9	338·5	±5·6
	45·5	339·2	315·7	−23·5			
	43·4	331·8	319·2	−12·6			
	42·8	312·8	320·0	+ 7·2			
	43·3	312·3	319·3	+ 7·0			
	44·0	314·5	318·2	+ 3·7			
	44·8	304·9	316·9	+12·0			
	47·7	273·9	311·8	+37·9			
Mar. 21.	36·3	298·3	293·2	− 5·1	± 5·1	302·3	±3·0
	37·4	295·5	292·0	− 3·5			
	39·8	280·8	289·5	+ 8·7			
Mar. 22.	42·9	289·2	286·7	− 2·5	± 2·6	303·4	±1·2
	44·1	284·7	285·1	+ 0·4			
	45·3	289·3	283·3	− 6·0			
	48·2	277·4	278·6	+ 1·2			
	54·3	264·9	267·2	+ 2·3			
	56·3	258·0	263·0	+ 5·0			
Mar. 24.	59·3	353·1	345·7	− 7·4	± 4·2	409·8	±2·1
	51·5	359·1	368·3	+ 9·2			
	53·5	361·6	363·1	+ 1·5			
	54·5	361·2	360·4	− 0·8			
	56·9	356·6	353·6	− 3·0			
Mar. 26.	68·1	250·7	......	......	......	342·7	
Apr. 15.	57·1	57·8	54·7	− 3·1	± 2·1	65·52	±1·46
	59·3	50·4	53·6	+ 3·2			
	61·4	52·3	52·3	0·0			
Apr. 18.	38·8	175·8	172·2	− 3·6	± 3·3	179·1	±1·3
	42·2	166·1	169·8	+ 3·7			
	45·3	161·1	167·3	+ 6·2			
	46·8	163·9	165·9	+ 2·0			
	56·3	158·8	155·2	− 3·6			
	58·3	153·1	152·7	− 0·4			
	60·3	155·9	149·5	− 6·4			
	64·4	145·9	140·8	− 5·1			
	66·7	128·7	135·0	+ 6·3			

Note.—The notes, which are the same as for the unreduced observations, will be found at pp. 589–592.

The observations of each night are now represented by a single quantity, so that, after allowing for the varying distance of the moon from the earth and sun, they will be available for determining the rate of change of the moon's radiant heat with her phase: In the following Table the values of log z* are arranged in order of ε. Column I. gives the astronomical date, column II. the apparent elongation from full moon (— before full moon, + after), column III. the log z; column IV. contains twice the logarithm of the moon's radius-vector (ϱ) from the earth, the radius-vector of the moon when her horizontal parallax is 57′ being taken as unity; column V. contains twice the logarithm of the moon's distance (R') from the sun *, the mean distance of the earth being taken as unity.

---

* See column VII. of the foregoing Table.

The natural number, z', corresponding to the sum of the quantities given in columns III., IV., and V., or the observed mean heating-effect on each night reduced to the zenith, is given in column VI.; in VII. is given w, the number of sets of observations, each set consisting of ten determinations, from which z' has been deduced; and in IX. the difference between columns VI and VIII.

Reduction of daily means to a mean distance of the Sun and Moon, and comparison with Curve. (See also Plate XLVIII., A.)

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
1800+	ε.	log z.	log ϱ^2.	log R'^2.	z' observed.	w=No. of sets.	z' curve.	C−O.	$\frac{100}{z'}$(C−O).
Mar. 24, 71.	−138° 0′	....	....	....	0·0	2	......	......	......
Mar. 27, 71.	−105 19	1·5457	0·0356	9·9982	38·0	10	38·0	0·0	0·0
Mar. 28, 71.	− 94 0	1·6764	0·0307	9·9988	50·8	8	54·2	+ 3·4	+ 6·3
Apr. 15, 72.	− 89 47	1·8029	0·0352	0·0037	69·5	3	63·8	− 5·7	− 8·9
Feb. 16, 72.	− 83 12	1·9284	0·0283	9·9902	88·5	6	80·7	− 7·8	− 9·7
Mar. 29, 71.	− 82 33	1·8376	0·0229	9·9995	72·4	10	82·3	+ 9·9	+12·0
Dec. 19, 71.	− 78 20	1·9938	0·0029	9·9862	96·1	3	93·7	− 2·4	− 2·6
Jan. 18, 72.	− 74 11	2·0443	0·0221	9·9866	113·0	7	105·1	− 7·9	− 7·5
May 28, 71.	− 72 14	2·0134	9·9800	0·0126	101·4	6	110·5	+ 9·1	+ 8·2
Dec. 20, 71.	− 66 8	2·1493	0·0151	9·9865	141·6	7	128·8	−12·8	− 9·9
Jan. 19, 72.	− 63 7½	2·1441	0·0275	9·9870	144·1	2	138·5	− 5·6	− 4·0
May 29, 71.	− 59 55	2·1412	9·9661	0·0131	131·9	4	149·3	+17·4	+11·6
Apr. 18, 72.	− 56 11	2·2531	0·0164	0·0057	188·5	9	162·5	−26·0	−16·0
Apr. 30, 71.	− 53 46	2·3579	9·9753	0·0082	219·5	6	171·5	−48·0	−28·0
Jan. 20, 72.	− 50 56	2·3380	0·0366	9·9876	230·2	2	182·3	−47·9	−26·3
Mar. 2, 71.	− 49 36	2·0628	0·0145	9·9943	118·0	4	187·6	+69·6	+37·1
May 30, 71.	− 45 37	2 2821	9·9527	0·0138	177·2	2	203·8	+26·6	+13·0
Feb. 20, 72.	− 38 9	2·3588	0·0365	9·9924	244·1	4	236·3	− 7·8	− 3·3
Mar. 21, 72.	− 36 42	2·4804	0·0173	9·9993	314·1	3	243·0	−71·1	−29·3
Jan. 22, 72.	− 28 44	2·2988	0·0388	9·9883	211·8	3	282·6	+70·8	+25·0
Mar. 22, 72.	− 24 27	2·4820	0·0100	9·9998	310·4	6	307·0	− 3·4	− 1·1
Apr. 3, 71.	− 21 31	2·5387	9·9628	0·0025	319·2	8	325·5	+ 6·3	+ 1·9
June 1, 71.	− 17 29	2·6021	9·9346	0·0145	355·8	4	351·4	− 4·4	− 1·3
May 3, 71.	− 14 16	2·5966	9·9397	0 0097	351·6	2	371·4	+19·8	+ 5·3
Dec. 25, 71.	− 10 16	2·5830	0·0366	9·9876	404·8	7	393·1	−11·7	− 3·0
Mar. 24, 72.	− 4 9	2·6126	9·9940	0·0005	404·7	5	407·2	+ 2·5	+ 0·6
June 2, 71.	− 3 42	2·7054	9·9312	0·0148	448·1	3	407·2	−40·9	−10·0
Dec. 26, 71.	+ 0 45	2·5478	0·0385	9·9877	375·0	3	401·4	+26·4	+ 6·6
Feb. 24, 72.	+ 8 33	2·5295	0·0107	9·9936	341·8	8	373·1	+31·3	+ 8·4
Dec. 28, 71.	+ 23 28	2·4819	0·0337	9·9874	318·4	7	307·5	−10·9	− 3·5
Mar. 26, 72.	+ 24 44	2·5349	9·9806	0·0008	328·3	1	301·8	−26·5	− 8·8
Jan. 27, 72.	+ 25 19	2·5528	0·0306	9·9888	373·5	1	299·2	−74·3	−24·8
Nov. 1, 71.	+ 52 2	2·1920	0·0363	9·9943	166·9	4	182·9	+16·0	+ 8·7
Jan. 30, 72.	+ 61 53	2·2146	0·0003	9·9882	159·6	6	149·0	−10·6	− 7·1
Jan. 2, 72.	+ 82 30	1·9965	9·9963	9·9856	95·2	2	96·5	+ 1·3	+ 1·3
Feb. 1, 72.	+ 87 54	1·9668	9·9778	9·9876	85·6	1	83·1	− 2·5	− 3·0
Jan. 5, 72.	+119 51	1·3922	9·9598	9·9843	21·7	2	21·7	0·0	0·0

---

* The linear distance of the moon from the sun is readily obtained from the earth's radius-vector by the formula

$$\text{Moon's distance from sun} = R' = R + \frac{8''{\cdot}95}{P} \cos \varepsilon,$$

where R is the earth's radius-vector, P the moon's equatorial horizontal parallax, and ε the moon's elongation from full; in our case we have adopted a mean value of P=3420″, so that $R' = R + [7{\cdot}4178] \cos \varepsilon$ nearly.

The values of z' were now laid down as ordinates with those of ε as abscissæ, the weight being indicated on the plan previously mentioned. A curve was then carefully drawn and read off and then compared with the observations; in this way small corrections for the curve were deduced, and finally the following Table adopted as giving the best representation of the observations. (See also Plate XLVIII., A.)

Phase Table.

ε.	z′.		ε.	z′.		ε.	z′.		ε.	z′.	
−106°	37·5	1·5 930	−48°	194·0	8·2	+10°	366·9	8·8	+68°	132·5	5·1 316
104	39·0	2·1	46	202·2	8·4	12	358·1	8·8	70	127·4	5·0
102	41·1	2·6 108	44	210·6	8·6	14	349·3	8·8	72	122·4	5·0
100	43·7	3·0	42	219·2	8·8	16	340·5	8·8	74	117·4	4·9
98	46·7	3·6	40	228·0	9·0 565	18	331·7	8·9	76	112·5	4·9
96	50·3	3·9	38	237·0	9·3	20	322·8	8·8 800	78	107·6	4·9
94	54·2	4·4	36	246·3	9·6	22	314·0	8·9	80	102·7	5·0 255
92	58·6	4·7	34	255·9	9·9	24	305·1	8·9	82	97·7	4·9
90	63·3	4·8 157	32	265·8	10·2	26	296·2	8·9	84	92·8	5·0
88	68·1	5·1	30	276·0	10·6 684	28	287·3	8·9 690	86	87·8	4·9
86	73·2	5·3	28	286·6	11·2	30	278·4	8·9	88	82·9	4·9
84	78·5	5·3	26	297·8	11·9	32	269·5	8·8	90	78·0	4·9 193
82	83·8	5·4	24	309·7	12·7	34	260·7	8·9	92	73·1	4·8
80	89·2	5·4 221	22	322·4	12·9	36	251·8	8·9	94	68·3	4·8
78	94·6	5·5	20	335·3	12·9 831	38	242·9	8·8	96	63·5	4·7
76	100·1	5·5	18	348·2	12·7	40	234·1	8·9 580	98	58·8	4·5
74	105·6	5·6	16	360·9	12·1	42	225·2	8·9	100	54·3	4·3 1347
72	111·2	5·8	14	373·0	11·3	44	216·3	8·7	102	50·0	4·1
70	117·0	6·0 290	12	384·3	10·0	46	207·6	8·6	104	45·9	3·9
68	123·0	6·2	10	394·3	7·7 978	48	199·0	8·2	106	42·0	3·7
66	129·2	6·4	8	402·0	4·2	50	190·8	7·8 473	108	38·3	3·5
64	135·6	6·6	6	406·2	+1·1	52	183·0	7·6	110	34·8	3·3 0863
62	142·2	6·8	4	407·3	−1·0 1,010	54	175·4	7·4	112	31·5	3·0
60	149·0	7·0 369	− 2	406·3	3·0	56	168·0	6·9	114	28·5	2·6
58	156·0	7·2	0	403·3	5·0	58	161·1	6·4	116	25·9	2·3
56	163·2	7·4	+ 2	398·3	6·7	60	154·7	6·1 384	118	23·6	2·0 536
54	170·6	7·6	4	391·6	7·9	62	148·6	5·6	+120	21·6	
52	178·2	7·8	6	383·7	8·3	64	143·0	5·3			
50	186·0	8·0 461	8	375·4	8·5 915	66	137·7	5·2			
− 48	194·0		+10	366·9		+68	132·5				

From this Table the numbers in column VIII. were taken out. Column IX. shows the difference between curve and observation; and for the purpose of giving a better idea of the degree of agreement, the percentage error is given in column X. The sum of $w\left\{\frac{100}{z'}(\mathrm{C}-\mathrm{O})\right\}^2$ is 25917·4, and the number of nights, omitting the first two and the last, is 34; whence the mean percentage error of a single set of ten readings has been calculated on the usual assumption that the errors are inversely proportional to the square root of the number of sets.

This mean error is ±28·02 per cent., corresponding to a probable error of ±18·9 per cent. The average number of sets is 4·7; this gives ±12·9 per cent. for the mean and ±8·7 per cent. for the probable error of a night's observations; a comparison of these numbers with column IX., however, shows that large constant errors were doubtless prevalent on many nights, so that any increase of the number of sets was almost powerless to obtain a more reliable result. Irrespective of the number of sets and excluding, as a matter of course, the first and last determinations, the mean error is ±10·4 per cent.

For the sake of comparison we may state that SEIDEL found the probable error of a single complete determination (consisting of four readings of his photometer) of the relative brightness of two stars of the first magnitude to be $\frac{1}{12}$, or 8·3 per cent. By inspection of the curve it will be perceived that the maximum of heat appears to take place a little before full moon, but that the heat at the time of the first quarter is rather less than at the last quarter; and also that the average heat during the period from first quarter to full moon is less than during the corresponding period after full. Both these departures of the curve from symmetry on the two sides of the full appear somewhat too large to be ascribed entirely to accidental error in the observations. Possibly the considerable inequality in the distribution of the mountainous regions and the plains and so-called "seas" between the preceding and following halves of the moon's visible surface may be looked to as the cause; and it may be desirable to direct attention to this point in a future course of observations, but for the present it would evidently be premature to speculate further. As to the amount of the difference, it is found by examination of the curve that at the first quarter the amount is 63·3, and at the last quarter 78·0, that just before full moon being 407·3.

In conjunction with the foregoing experiments determinations of the proportion of the moon's heat transmitted by a plate of glass were occasionally made. The following is a Table corresponding to those at pp. 589–592 and 600–603 for the moon's unobstructed heat.

Journal and Reduction to zenith of observations made with glass plate interposed.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
1871.	Sidereal time.	Mean deviation (G').	Zenith-distance.	Observed G' corr.	G' calc.	Difference of columns V. and VI. C−O.	p.e.	Zenith-mean (z).	p.e$_z$.
	h m		°						
Apr. 3.	11 11	42·2	46·2	42·2	45·3	+3·1	±2·5	48·7	±1·2
	11 48	42·6	46·0	42·6	45·3	+2·7			
	12 27	47·6	47·1	47·6	45·1	−2·5			
	13 33	40·9	51·8	40·9	43·7	+2·8			
	15 23	40·1	64·7	40·1	38·2	−1·9			
	16 13	38·8	71·4	38·8	32·8	−6·0			
Apr. 30.	12 34	24·8	46·4	24·8	25·0	+0·2	±1·9	26·9	±1·1
	13 13	24·8	49·8	24·8	24·4	−0·4			
	14 16	18·6	56·7	18·6	23·2	+4·6			
	15 52	20·7	69·9	20·7	18·8	−1·9			
	16 34	18·2	75·8	18·2	15·6	−2·6			
May 3.	12 21	41·4	63·6	41·4	43·2	+1·8	±1·7	54·2	±1·5
	13 56	46·7	61·0	46·5	44·8	−1·7			
May 28.	15 10	8·5	62·4	8·5	8·5	0·0	±0·2	10·4	±0·2
	15 50	7·9	67·8	7·9	7·7	−0·2			
	16 23	6·4	72·5	6·4	6·8	+0·4			
May 30.	16 42	22·3	70·6	22·3	……	……	…..	32·4	
June 1.	16 13	42·0	70·2	42·0	43·8	+1·8	±2·1	63·1	±1·9
	16 52	40·2	72·0	40·2	41·7	+1·5			
	17 30	42·2	74·5	42·2	38·4	−3·8			
June 2.	16 8	63·6	73·9	63·6	63·5	−0·1	±0·1	102·0	±0·1
	16 48	63·1	74·0	63·1	63·2	+0·1			
Dec. 20.	2 22	12·7	50·5	12·7	……	……	……	14·0	
Dec. 25.	2 25	52·1	46·0	52·3	51·7	−0·6	±0·5	55·5	±0·3
	2 56	51·6	41·9	51·7	52·7	+1·0			
	3 31	54·3	37·8	54·3	53·6	−0·7			
	4 45	54·5	31·5	54·3	54·6	+0·3			
Dec. 28.	4 53	40·4	47·5	40·4	34·0	−6·4	±3·0	36·8	±1·6
	5 31	34·5	42·6	34·4	34·9	+0·5			
	9 9	34·0	32·1	34·1	36·2	+2·1			
	9 45	32·2	34·8	32·3	35·9	+3·6			
1872. Feb. 24.	12 37	41·5	46·2	41·5	41·1	−0·4	±0·4	44·3	±0·3
	13 15	39·8	49·8	39·9	40·3	+0·4			
Mar. 21.	10 27	34·3	36·7	34·3	31·8	−2·5	±2·5	32·9	±1·7
	10 59	29·2	38·2	29·2	31·7	+2·5			
Mar. 22.	12 40	32·7	46·7	32·7	32·4	−0·3	±0·4	34·9	±0·3
	13 13	31·0	50·0	31·0	31·7	+0·7			
	14 21	30·1	58·5	30·1	29·7	−0·4			
Mar. 24.	14 5	48·8	55·5	48·8	……	…..	……	55·9	
Apr. 18.	11 14	16·7	39·7	16·8	16·3	−0·5	±0·5	17·0	±0·4
	12 9	15·5	43·6	15·5	16·0	+0·5			

The corrections for the changes of the moon's phase and semidiameter during the observations were very small, on which account the particulars are omitted, as also the adopted mean elongation, semidiameter, and sidereal time, which are the same as for the total heat determinations. The observations are satisfactorily represented in altitude by the Table already deduced. Although these results were fully examined by means of a curve like that for the total heat, it is not necessary to give further particulars here, as these observations will afterwards be combined with others, of which we must now give an account.

Observations made during the Autumn of 1870.

The preceding investigations having thus given, at least, a tolerably close approximation to the law of the extinction of the moon's radiant heat in our atmosphere, and the extent to which its amount is influenced by her change of phase, we are in a position to make use of a compact series of observations made in the autumn of 1870. These are, as a rule, confined to low altitudes; and the range on any given night is, with one or two exceptions, so small that they could not have been used with advantage in the construction of the altitude curve, nor, owing to alterations in the height of the directive magnet of the galvanometer, were they at once available for the determination of, or comparison with, the phase curve. However, as they were made for the most part under very favourable circumstances of weather, and as from their chiefly referring to the waning moon they are important as filling an all but vacant gap in the records of 1871–72, they are introduced here, although out of their chronological order. The particulars of the observations are arranged in nearly the same way as those already discussed, the only difference being that the sets taken with a plate of glass interposed are left in their original place in the journal. As a matter of convenience, and on account of its greater accordance with fact, the Phase Table at p. 605 was used in place of LAMBERT's formula for the correction for the change of phase. The Table of ϕz was used for reducing to the zenith. In this way the quantities in column "log (G corr.)" were obtained.

Occasionally the time of observation was not noted, but it could generally be determined with sufficient accuracy from the measured altitudes of the moon. As has been already mentioned, some uncertainty exists as to the height at which the directive magnet was placed on some nights; but as it was always used in one or other of two positions (3·00 or 3·46 inches), the directive force on the needle being as little as 0·6579 in one position as compared with unity in the other, little anxiety can arise as to the correctness of the assumptions made.

The following Tables contain the Journal of Observations and their reductions, which will be readily understood on comparison with those already given.

Journal of Observations and Preliminary Reductions.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.
			The Moon's							The adopted mean		
1870.	Sidereal time.	Observed deviation (G.).	ε.	Apparent zenith-distance.	Apparent semi-diameter.	log (*g*).	log (ε).	log (σ).	log (G corr.).	Sidereal time.	ε.	Apparent semi-diameter.
	h m		° ′	°	′ ″					h m	° ′	′ ″
Aug. 8.	19 13	97·8.	−30 33	76·4	15 56·1	9·9998	0·0019	0·0000	1 9920	19 45·0	−30 19	15 56·0
	19 31	83·0	−30 25	76·5	15 56·1	9·9999	0·0008	0·0000	1·9198			
*	20 1	77·4	−30 13	77·0	15 56·0	9·9999	9·9991	0·0000	1·8877			
† *gl*	20 13	11·0	−30 8	77·4	15 55·9	0·0000	9·9984	0 0000	1·0398			
Aug. 10‡.	20 29	162·7 *gl* 36·0	− 5 59	73·3	15 40·0	9·9995 0·0000	0·0000	0·0000	2·2109	20 29·0	− 5 59	15 40·0
Aug. 11.	21 18	173 4	+ 8 29	70·0	15 30·8	9 9995	9·9992	0·0000	2·2377	21 50·0	+ 8 39	15 30·8
§ *gl*	21 33	34·7	+ 8 34	69·8	15 30·8	0·0000	9·9996	0·0000	1·5399			
	21 48	166·6	+ 8 38	69·6	15 30·8	9·9995	9·9999	0·0000	2·2211			
gl	22 3	32·3	+ 8 43	69·5	15 30·9	0·0000	0·0003	0·0000	1·5095			
	22 28	155·9	+ 8 51	69·7	15 30·9	9·9996	0·0010	0·0000	2·1934			
Aug. 12.	19 55	133·6	+19 35	75·8	15 19·6	9·9997	9·9956	0·0022	2·1233	22 0·0	+20 19	15 21·9
‖	21 35	172·6	+20 10	67·5	15 21·6	9·9995	9·9991	0·0002	2·2358			
¶ *gl*	21 52	27·9	+20 16	66·8	15 21·8	0·0000	9 9997	0·0002	1·4455			
	22 9	181·3	+20 22	66·2	15 22·0	9·9994	0·0003	0 0000	2·2581			
gl	22 25	32·0	+20 27	65·8	15 22·0	0·0000	0·0008	0·0000	1·5059			
	22 40	181·6	+20 32	65·5	15 22·1	9·9994	0·0013	0·0000	2·2598			
Aug. 13.	19 49	74·7	+31 0	78·2	15 10·2	9·9999	9 9954	0·0028	1·8714	20 30·0	+31 38	15 12·9
** *gl*	20 15	15·1	+31 10	75·0	15 11·0	0·0000	9·9966	0·0020	1·7776			
	20 27	102·8	+31 15	73·6	15 11·4	9·9998	9·9971	0·0016	2·0105			
gl	20 45	16·5	+31 22	71·6	15 11·8	0·0000	9·9980	0·0012	1·2167			
	21 4	124·7	+31 28	69·7	15 12·3	9·9997	9·9987	0·0008	2·0951			
	22 49	145·2	+32 4	62·0	15 14·1	9·9996	0·0029	9·9992	2·1637			
gl	23 4	21 0	+32 8	61·5	15 14·3	0·0000	0·0034	9·9990	1·3246			
	23 19	148·9	+32 12	61·1	15 14·3	9·9996	0·0038	9·9990	2·1753			
Aug. 14.	21 6	146·7	+42 49	70·3	15 4·2	9·9996	9·9982	0 0008	2·1651	21 40·0	+43 2	15 5·0
†† *gl*	21 21	14·5	+42 55	68·6	15 4·6	0·0000	9·9990	0·0004	1·1608			
	21 37	147·2	+43 0	66·9	15 5·0	9·9996	9·9997	0·0000	2·1672			
gl	21 51	15·4	+43 6	65·4	15 5·3	0 0000	0·0006	9·9998	1·1879			
	22 16	142·0	+43 14	62·9	15 6·1	9·9996	0 0018	9·9988	2·1525			

* Aug. 8.—No mention of cloud. At $20^h\ 1^m$ the directive magnet was at 3·46 in.; the reading has already been reduced to what it would have been with the magnet at 3·00 in. See preceding page.

† $20^h\ 13^m$. This and all subsequent experiments marked *gl* were made with the glass plate interposed.

‡ Aug. 10.—Sky more or less streaky all night. The only available observations on this night were three sets, giving 252·1, *gl* 54·7, and 242·5 with the magnet at 3·46 in., for which the sidereal time $20^h\ 29^m$ has been adopted as best suiting the recorded altitudes.

§ Aug. 11.—The original readings were taken with the magnet at 3·46 in.; the proper reduction to 3·00 in. has been made. Sky slightly streaky all this night.

‖ Aug. 12.—There is no mention of the height of the magnet on this and the following night; but as the observations were made with it at 3·46 in. on the 11th and 14th, it is assumed to have been at the same height on the 12th and 13th.

¶ The telescope not on the moon for about half a minute.

** Aug. 13.—Magnet at 3·46 in., observations reduced to 3·00 in.

†† Aug. 14.—E.N.E. wind all night; galvanometer very unsteady. The magnet mentioned as being at 3·46 in.; observations reduced to 3·00 in.

TABLE (continued).

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.
1870.	Sidereal time.	Observed deviation (G.).	The Moon's			log (g).	log (ε).	log (σ).	log (G corr.).	The adopted mean		
			ε.	Apparent zenith-distance.	Apparent semi-diameter.					Sidereal time.	ε.	Apparent semi-diameter.
	h m		° ′	°	′ ″					h m	° ′	′ ″
Aug. 15.	22 3	107·6	+54 20	64·9	14 59·2	9·9998	9·9977	0·0008	2 0302	22 45·0	+54 35	15 0·2
* *gl*†	22 30	7·1	+54 26	62·9	14 59·6	0·0000	9·9987	0·0004	0·8504			
	22 45	109·1	+54 35	60·2	15 0·2	9·9998	0·0000	0·0000	2·0376			
gl	23 9	10·5	+54 43	57·8	15 0·7	0·0000	0·0013	9·9996	1·0221			
	23 29	112·1	+54 50	56·2	15 1·0	9·9998	0 0024	9·9992	2·0510			
gl	23 58	11·9	+55 0	54·0	15 1·5	0·0000	0·0039	9·9986	1·0780			
Aug. 16.	22 51	88·8	+65 34	60·6	14 56·1	9·9999	9·9982	0 0010	1·9475	23 26·0	+65 47	14 57·1
gl	23 6	9·5	+65 40	58·7	14 56·5	0·0000	9·9990	0·0006	0·9773			
	23 26	95·2	+65 47	56·4	14 57·1	9·9999	0·0000	0 0000	1·9785			
gl	23 46	9·7	+65 54	54·3	14 57·4	0 0000	0·0009	9 9996	0·9873			
	0 1	98·7	+65 59	52·9	14 57·8	9·9999	0·0016	9·9992	1·9950			
gl	0 16	9·7	+66 4	51·6	14 58·0	0·0000	0·0022	9·9990	0·9880			
Aug. 19.	0 9	34·8	+99 0	60·0	15 1·4	0·0000	9·9954	0·0012	1·5383	0 50·0	+99 16	15 2·7
‡ *gl*	0 26	3·1	+99 7	57·5	15 2·0	0·0000	9·9978	0·0006	0·4863			
	0 46	55·3	+99 15	54·7	15 2·6	0·0000	9·9997	0·0000	1·5311			
gl	1 11	2·6	+99 24	51·4	15 3·2	0·0000	0·0024	9·9904	0·4139			
	1 33	55·6	+99 32	48·5	15 3·8	0·0000	0·0047	9·9088	1·5375			
Oct. 4.	20 53	96·7	−54 22	72·5	15 27·0	9·9998	0·0023	0·0001	1·9876	21 38·0	−54 5	15 27·1
§ *gl*	21 23	13·8	−54 11	72·1	15 27·1	0·0000	0·0008	0·0000	1·1407			
	21 43	98·8	−54 3	72·2	15 27·1	9·9998	9·9998	0·0000	1·9944			
gl	22 5	12·9	−53 55	72·4	15 27·0	0·0000	9·9988	0·0001	1·1095			
	22 17	105·4	−53 50	72·7	15 26·9	9·9998	9·9981	0·0002	2·0210			
Oct. 9.	22 33	349·3	+ 6 31	61·3	14 56·9	9·9979	9·9993	0·0012	2·5416	23 33·0	+ 6 40	14 58·1
‖ *gl*	23 3	62·7	+ 6 36	58·2	14 57·6	9·9999	9·9997	0·0004	1·7973			
	23 25	370·4	+ 6 39	56·1	14 58·0	9·9976	0·0000	0·0000	2·5663			
gl	23 43	61·4	+ 6 42	54·6	14 58·3	9·9999	0·0002	9·9998	1·7881			
	23 56	389·6	+ 6 44	53·7	14 58·5	9·9973	0·0004	9·9996	2·5879			
gl	0 8	62·0	+ 6 46	52·8	14 58·7	9·9999	0·0006	9·9994	1·7923			
	0 20	385·9	+ 6 48	52·2	14 58·8	9·9974	0·0007	9·9992	2·5838			
Oct. 10.	22 45	** 337·8	+15 56	61·5	14 52·6	9·9980	9·9988	0·0008	2·5252	23 53·0	+16 8	14 53·5
¶ *gl*	23 5	47·4	+16 3	59·0	14 53·1	0·0000	9·9995	0·0004	1·6757			
	23 25	311·3	+16 9	56·7	14 53·6	9·9983	0·0001	9·9998	2·4914			
gl	23 47	46·2	+16 16	54·3	14 54·1	0·0000	0·0009	9·9996	1·6651			
	0 0	321·4	+16 20	52·8	14 54·4	9·9982	0·0013	9·9992	2·5057			

* Aug. 15.—N.E. wind all night; hazy sky; the moon was orange-coloured when low. No mention of the height of the directive magnet; it is assumed to have been at 3·00 in., as was the case on the following night.

† $22^{h}\ 30^{m}$. Galvanometer very unsteady.

‡ Aug. 19.—The scale was 38½ inches from the galvanometer; therefore the readings have been multiplied by $\frac{36\cdot0}{38\cdot5}$ to reduce them to the usual distance of the scale, and by 0·6579 to reduce them to a height of 3·00 in. of the directive magnet.

§ Oct. 4.—New speculum used for the first time. Magnet at 3·46 in., observations reduced to 3·00 in. Apparently clear, but still a slight fog which makes the moon's image faint although still sharp.

‖ Oct. 9. Magnet at 3·46 in., observations reduced to 3·00 in.

¶ Oct. 10.—Magnet at 3·46 in., observations reduced to 3·00 in.

** The single readings vary more than 20 per cent.

Observations without glass plate; reductions to zenith.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
1870.	Apparent zenith-distance.	Observed G. corr.	G. calc.	C−O.	*p.e.*	Zenith-mean (*z*).	*p.e.*$_z$.
Aug. 8.	76°·4	98·2	87·2	−11·0	± 6·6	154·4	± 6·8
*	76·5	83·1	86·8	+ 3·7			
	77·0	77·2	84·8	+ 7·6			
Aug. 10. *	73·3	162·5	......	......	......	256·0	......
Aug. 11.	70·0	172·9	164·1	− 8·8	± 9·0	234·8	± 8·4
*	69·6	166·3	165·8	− 0·5			
	69·7	156·1	165·4	+ 9·3			
Aug. 12.	75·8	132·8	135·7	+ 2·9	± 1·8	234·3	± 1·2
*	67·5	172·1	173·7	+ 1·6			
	66·2	181·1	178·3	− 2·8			
	65·5	181·9	180·7	− 1·2			
Aug. 13.	78·2	74·4	89·2	+14·8	± 6·2	172·8	± 3·9
*	73·6	102·4	108·6	+ 6·2			
	69·7	124·5	121·7	− 2·8			
	62·0	145·7	141·1	− 4·6			
	61·1	149·7	142·8	− 6·9			
Aug. 14.	70·3	146·2	133·6	−12·6	± 8·7	192·7	± 6·7
*	66·9	147·0	144·6	− 2·4			
	62·9	142·1	155·2	+13·1			
Aug. 15.	64·9	107·2	103·1	− 4·1	± 2·4	132·3	± 1·6
*	60·2	109·0	110·5	+ 1·5			
	56·2	112·5	114·8	+ 2·3			
Aug. 16.	60·6	88·6	90·9	+ 2·3	± 1·4	109·2	± 0·9
	56·4	95·2	94·7	− 0·5			
	52·9	98·9	97·2	− 1·7			
Aug. 19.	60·0	34·5	32·7	− 1·8	± 1·1	39·1	± 0·7
*	54·7	34·0	34·3	+ 0·3			
	48·5	34·5	35·8	+ 1·3			
Oct. 4.	72·5	97·2	100·2	+ 3·0	± 3·2	153·8	± 2·8
*	72·2	98·7	101·1	+ 2·4			
	72·7	105·0	99·6	− 5·4			
Oct. 9.	61·3	348·0	353·2	+ 5·2	± 4·0	428·5	± 2·3
*	56·1	368·4	372·1	+ 3·7			
	53·7	387·2	379·1	− 8·1			
	52·2	383·5	383·2	− 0·3			
Oct. 10.	61·5	*335·2	307·5	−27·7	±15·9	374·1	±10·6
*	56·7	310·0	323·2	+13·2			
	52·8	320·4	333·2	+12·8			

* The remarks will be found at pp. 609 and 610.

Observations with glass plate; reductions to zenith.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
1870.	Apparent zenith-distance.	Observed G. corr.	G. calc.	C−O.	*p.e.*	z'.	$p.e_z$.
Aug. 8.	77°·4	11·0	……	……	……	20·4	……
Aug. 10.	73·3	36·0	……	……	……	56·7	……
Aug. 11.	69·8 69·5	34·7 32·3	33·4 33·6	−1·3 +1·3	±1·3	47·5	±1·3
Aug. 12.	66·8 65·8	27·9 32·0	29·7 30·3	+1·8 −1·7	±1·7	39·5	±1·6
Aug. 13.	75·0 71·6 61·5	15·0 16·5 21·1	15·1 16·9 20·7	+0·1 +0·4 −0·4	±0·3	25·2	±0·2
Aug. 14.	68·6 65·4	14·5 15·4	14·4 15·4	−0·1 0·0	±0·1	20·0	±0·1
Aug. 15.	62·9 57·8 54·0	7·1 10·5 12·0	9·4 10·0 10·3	+2·3 −0·5 −1·7	±1·4	11·7	±0·9
Aug. 16.	58·7 54·3 51·6	9·5 9·7 9·7	9·3 9·7 9·9	−0·2 0·0 +0·2	±0·1	11·0	±0·1
Aug. 19.	57·5 51·4	3·1 2·6	2·8 2·9	−0·3 +0·3	±0·3	3·2	±0·2
Oct. 4.	72·1 72·4	13·8 12·9	13·4 13·3	−0·4 +0·4	±0·4	20·3	±0·4
Oct. 9.	58·2 54·6 52·8	62·7 61·4 62·0	60·5 62·3 63·2	−2·2 +0·9 +1·2	±1·3	70·9	±0·8
Oct. 10.	59·0 54·3	47·4 46·2	45·8 47·7	−1·6 +1·5	±1·5	54·2	±1·2

Before these results can be compared with each other, it is necessary to examine into another source of uncertainty, which, however, as will be seen, can not only be got rid of, but even made to yield a most interesting result. During the month of August an old and consequently tarnished speculum was used; this was replaced by one of great brilliancy before the observations of October were commenced. Hence the readings taken in August are below, and those in October above what they would have been with a mirror of ordinary working quality. Taking these facts into consideration, the observations were divided into two groups, according as they were made with the old or new speculum; and by comparing these groups with the Phase Table for 1871–72, at p. 605, the following values of speculum factors for reducing the observations to the standard mirror of those years were obtained. The weight which has been attached to the factor of each day varies directly as the square root* of the number of sets, and inversely as the reduction to the zenith, October 4th having only half weight on account of bad weather.

Observations without glass plate.

1870.	Speculum-factor.	Weight.
Aug. 8	1·806	0·9677
10	1·560	0·8982
11	1·530	1·2170
12	1·298	1·4270
13	1·456	1·5620
14	1·046	1·3010
15	1·185	1·4330
16	1·140	1·4940
19	1·314	1·5190

Whence August speculum-factor without glass plate = 1·345; weight 11·82.

In the same way:—

1870.	Speculum-factor.	Weight.
Oct. 4	1·090	0·5645
„ 9	0·822	1·7360
„ 10	0·833	1·4880

Whence October speculum-factor without glass plate = 0·866; weight 3·79 †.

These factors may also be deduced, though with less certainty, from the experiments with the glass plate for those elongations within the range of the observations of 1871–72.

1870.	Speculum-factor.	Weight.
Aug. 8	1·818	0·5386
„ 10	1·300	0·6351
„ 11	1·030	0·9970
„ 12	0·880	1·0740

Whence August speculum-factor with glass plate = 1·164; weight 3·24.

In the same way:—

1870.	Speculum-factor.	Weight.
Oct. 4	1·042	0·4837
„ 9	0·722	1·1801
„ 10	0·661	1·0868

Whence October speculum-factor with glass plate = 0·867; weight 2·75.

These four factors must be kept separate, because in 1870 the glass plate was always warmed at the fire in order to dissipate any accidental film of moisture, while in the subsequent years it was merely kept in a dry room and then briskly rubbed with cotton-wool before being placed in the telescope. The quantity of heat transmitted by the glass is greater in the former case than in the latter.

---

* This ratio was used as tending to lessen the preponderance of any given day.

† Combining the factors for experiments without glass plate, it appears that a new speculum reflects 1·55, say *once and a half* as much heat as the most tarnished one that would be considered serviceable.

The results for 1870 can now be arranged like those for 1871–72; but, in addition to the reductions to a mean distance of the sun and moon, the speculum-factors must be applied. We have thus the following summary, where

$$\log \Sigma \text{ corr.} = \log \varrho^2 + \log R'^2 + \log \text{speculum-factor.}$$

Observations reduced to a mean distance of the Sun and Moon compared with Curve.

1870.	ε.	log Σ corr.	z' (obs.).	No. of sets.	1871–72. z' (curve).	C−O.	$\frac{100}{z'}$(C−O).
Oct. 4.	−54° 5′	9·9443	135·3	3	170·3	+35·0	+25·9
Aug. 8.	−30 19	0·1217	204·4	3	274·3	+69·9	+34·2
„ 10.	− 5 59	0·1364	350·3	2	406·2	+55·9	+16·0
Oct. 9.	+ 6 40	9·9715	401·4	4	381·0	−20·4	− 5·1
Aug. 11.	+ 8 39	0·1448	327·7	3	372·8	+45·1	+13·8
Oct. 10.	+16 8	9·9756	353·7	3	339·9	−13·8	− 3·9
Aug. 12.	+20 19	0·1527	333·0	4	321·4	−11·6	− 3·5
„ 13.	+31 38	0·1610	250·3	5	271·1	+20·8	+ 8·3
„ 14.	+43 2	0·1681	283·8	3	220·6	−63·2	−22·3
„ 15.	+54 35	0·1722	196·6	3	173·2	−23·4	−11·9
„ 16.	+65 47	0·1737	163·0	3	138·4	−24·6	−15·1
„ 19.	+99 16	0·1674	57·4	3	56·0	− 1·4	− 2·4

z' (obs.) is the zenith-value of the total heat for a mean distance of the sun and moon and for an average speculum;

z' (curve) is taken from the curve derived from the results of 1871–72;

C−O is the difference between curve and observation, and $\frac{100}{z'}$(C−O) is the percentage difference.

The deviation of the total heat-results from the curve of 1871–72 are within such moderate limits, that, taking into consideration the way in which the speculum-factors were derived from it, it does not appear advisable to alter its course in order to attempt a still closer representation of the whole of the observations.

The following Table gives a summary of all the observations made with the glass plate interposed, during the years 1870, 1871, and 1872, of which the preliminary reductions have already been given.

Glass-plate observations reduced to a mean distance of the Sun and Moon, and compared with the Phase-Curves. (See also Plate XLVIII., Curve B.)

1800+	ε.	log z.	log Σ corr.	w=No. of sets.	z'' observation.	z'' curve.	C−O.	Percentage of moon's heat transmitted by glass. Observations.	Percentage of moon's heat transmitted by glass. Curves.	Numbers of sets.
May 28, 71.	−72° 14′	1·0175	0·9926	3	10·2	10·2	0·0	10·1	9·2	6 and 3
Dec. 20, 71.	−66 8	1·1472	0·0016	1	14·1	13·4	− 0·7	10·0	10·4	7 ,, 1
Apr. 18, 72.	−56 11	1·2301	0·0221	2	17·9	18·7	+ 0·8	9·5	11·5	9 ,, 2
Oct. 4, 70.	−54 5	1·3084	9·9447	2	17·9	19·9	+ 2·0	13·2	11·7	3 ,, 2
Apr. 30, 71.	−53 46	1·4297	9·9835	5	25·9	20·0	− 5·9	11·8	11·7	6 ,, 5
May 30, 71.	−45 37	1·5109	9·9665	1	30·0	24·3	− 5·7	16·9	11·9	2 ,, 1
Mar. 21, 72.	−36 42	1·5169	0·0166	2	34·2	29·1	− 5·1	10·9	12·0	3 ,, 2
Aug. 8, 70.	−30 19	1·3086	0·0589	1	23·3	33·3	+10·0	11·4	12·1	3 ,, 1
Mar. 22, 72.	−24 27	1·5434	0·0098	3	35·8	39·6	+ 3·8	11·5	12·9	6 ,, 3
Apr. 3, 71.	−21 31	1·6879	9·9653	6	45·0	43·9	− 1·1	14·1	13·5	8 ,, 6
June 1, 71.	−17 29	1·7999	9·9491	3	56·1	50·6	− 5·5	15·8	14·4	4 ,, 3
May 3, 71.	−14 16	1·7340	9·9494	2	48·2	56·6	+ 8·4	13·7	15·2	2 ,, 2
Dec. 25, 71.	−10 16	1·7446	0·0242	4	58·7	63·8	+ 5·1	14·5	16·2	7 ,, 4
Aug. 10, 70.	− 5 59	1·7535	0·0600	1	65·1	69·4	+ 4·3	18·6	17·1	2 ,, 1
Mar. 24, 72.	− 4 9	1·7473	9·9945	1	55·2	70·2	+15·0	13·6	17·2	5 ,, 1
June 2, 71.	− 3 42	2·0083	9·9460	2	90·0	70·3	−19·7	20·1	17·3	3 ,, 2
Oct. 9, 70.	+ 6 40	1·8509	9·9714	3	66·4	61·4	− 5·0	16·6	16·1	4 ,, 3
Feb. 24, 72.	+ 8 33	1·6462	0·0043	2	44·7	58·7	+14·0	13·1	15·7	8 ,, 2
Aug. 11, 70.	+ 8 39	1·6768	0·0686	2	55·6	58·6	+ 3·0	17·0	15·7	3 ,, 2
Oct. 10, 70.	+16 8	1·7339	9·9759	2	51·3	48·9	− 2·4	14·5	14·4	3 ,, 2
Aug. 12, 70.	+20 19	1·5963	0·0768	2	47·1	44·2	− 2·9	14·2	13·8	4 ,, 2
Dec. 28, 71.	+23 28	1·5661	0·0211	4	38 7	40·6	+ 1·9	12·1	13·2	7 ,, 4
Aug. 13, 70.	+31 38	1·4020	0·0853	3	30·7	31·9	+ 1·2	12·3	11·8	5 ,, 3
,, 14, ,,	+43 2	1·3004	0·0929	2	24·7	22·2	− 2·5	8·7	10·1	3 ,, 2
,, 15, ,,	+54 35	1·0681	0·0975	3	14·6	16·2	+ 1·6	7·4	9·4	3 ,, 3
,, 16, ,,	+65 47	1·0417	0·0996	3	13·9	13·0	− 0·9	8·5	9·4	3 ,, 3
,, 19, ,,	+99 16	0·5067	0·0951	2	4·0	4·0	0·0	7·0	7·1	3 ,, 2

Phase Table for observations with glass plate. (See Plate XLVIII., Curve B.)

ε.	z''.		ε.	z''.		ε.	z''.		ε.	z'.	
−74°	9·2	1·1	−30°	33·5	1·9	+14°	51·5	2·4	+58°	15·1	0·6
72	10·3	1·1	28	35·4	2·2	16	49·1	2·3	60	14·5	0·5
70	11·4	1·0	26	37·6	2·6	18	46·8	2·3	62	14·0	0·6
68	12·4	1·1	24	40·2	2·9	20	44·5	2·2	64	13·4	0·5
66	13·5	1·1	22	43·1	3·2	22	42·3	2·3	66	12·9	0·5
64	14·6	1·0	20	46·3	3·4	24	40·0	2·2	68	12·4	0·6
62	15·6	1·1	18	49·7	3·6	26	37·8	2·2	70	11·8	0·5
60	16·7	1·1	16	53·3	3·8	28	35·6	2·1	72	11·3	0·5
58	17·8	1·0	14	57·1	3·7	30	33·5	2·0	74	10·8	0·6
56	18·8	1·1	12	60·8	3·5	32	31·5	2·0	76	10·2	0·5
54	19·9	1·1	10	64·3	3·0	34	29·5	1·8	78	9·7	0·5
52	21·0	1·0	8	67·3	2·1	36	27·7	1·7	80	9·2	0·6
50	22·0	1·1	6	69·4	+0·9	38	26·0	1·6	82	8·6	0·5
48	23·1	1·0	4	70·3	0·0	40	24·4	1·5	84	8·1	0·6
46	24·1	1·1	− 2	70·3	−0·8	42	22·9	1·4	86	7·5	0·5
44	25·2	1·1	0	69·5	1·8	44	21·5	1·3	88	7·0	0·5
42	26·3	1·0	+ 2	67·7	2·5	46	20·2	1·1	90	6·5	0·6
40	27·3	1·1	4	65·2	2·8	48	19·1	1·0	92	5·9	0·5
38	28·4	1·1	6	62·4	2·9	50	18·1	0·9	94	5·4	0·5
36	29·5	1·2	8	59·5	2·8	52	17·2	0·8	96	4·9	0·6
34	30·7	1·3	10	56·7	2·7	54	16·4	0·7	98	4·3	0·5
32	32·0	1·5	12	54·0	2·5	56	15·7	0·6	+100	3·8	
−30	33·5		+14	51·5		+58	15·1				

Comparison of the reducing curve in zenith-distance with LAPLACE'S *law.*

As the observations of the moon's radiant heat were all made within a range of little more than 50° of zenith-distance, it is of interest to see if any of the more generally received formulæ for the extinction of heat or light in our atmosphere agree with the Table at p. 598; for only in the event of this being the case can we extend our considerations to some interesting cases not included within that range.

The best form for such a formula is doubtless that first given by LAPLACE*, and which is to be found in POUILLET'S 'Météorologie' (t. ii. p. 711) in the modified form

$$t=ap^{\varepsilon}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where t is the heat-effect in a given interval of time, and ε the amount of air through which the rays of heat have passed; a and p are constants to be determined from the observations; ε is calculated on the assumption that the atmosphere forms a coat of uniform density of a thickness h, which is taken equal to unity. If any value, r, for the radius of the earth be assumed, then ε can be calculated for any zenith-distance, z, by the formula

$$\varepsilon=\sqrt{2rh+h^2+r^2\cos^2 z}-r\cos z.$$

Substituting logarithms in (1), we have

$$\log t=\log a+\varepsilon\log p,$$

where for $\log t$ we can take φz with its sign changed, and thus get a series of equations:—

$$\left.\begin{aligned}-\varphi z &= \log a+\varepsilon\ \log p,\\ -(\varphi z)' &= \log a+\varepsilon'\ \log p,\\ -(\varphi z)'' &= \log a+\varepsilon''\log p,\\ \&c.&\qquad\qquad \&c.\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

whence $\log a$ and $\log p$ can be deduced. In his researches on the sun's radiant heat POUILLET assumed $r=80\,h$. In accordance with this the values of ε for every degree from 29° to 80° were calculated and the constants a and p deduced. It was then found that the values of φz were tolerably well represented, yet at the same time it was evident that $r=70\,h$ or $r=60\,h$ would fulfil the required conditions more accurately; and in point of fact $r=60\,h$ is very nearly the value that makes the outstanding errors in the representation of φz a minimum; $r=58\,h$ lessens the sum of the squares of the errors to an extent altogether immaterial. The following are the 51 equations of the form (2), where the coefficient of $\log p$ is

$$\varepsilon=\sqrt{121+3600\cos^2 z}-60\cos z.$$

---

[*] Mécanique Céleste, t. iv. livre x. chap. 3.

	$t-c.$
$-\ 0{\cdot}0046 = \log a + 1{\cdot}141 \log p$	$-\ 0{\cdot}0002$
$-\ 0{\cdot}0056 = \log a + 1{\cdot}152 \log p$	1
$-\ 0{\cdot}0067 = \log a + 1{\cdot}163 \log p$	2
$-\ 0{\cdot}0078 = \log a + 1{\cdot}176 \log p$	1
$-\ 0{\cdot}0090 = \log a + 1{\cdot}188 \log p$	2
$-\ 0{\cdot}0102 = \log a + 1{\cdot}202 \log p$	1
$-\ 0{\cdot}0115 = \log a + 1{\cdot}216 \log p$	1
$-\ 0{\cdot}0129 = \log a + 1{\cdot}231 \log p$	1
$-\ 0{\cdot}0143 = \log a + 1{\cdot}246 \log p$	2
$-\ 0{\cdot}0158 = \log a + 1{\cdot}263 \log p$	1
$-\ 0{\cdot}0174 = \log a + 1{\cdot}280 \log p$	1
$-\ 0{\cdot}0191 = \log a + 1{\cdot}298 \log p$	2
$-\ 0{\cdot}0209 = \log a + 1{\cdot}317 \log p$	2
$-\ 0{\cdot}0227 = \log a + 1{\cdot}337 \log p$	1
$-\ 0{\cdot}0247 = \log a + 1{\cdot}358 \log p$	2
$-\ 0{\cdot}0268 = \log a + 1{\cdot}380 \log p$	3
$-\ 0{\cdot}0290 = \log a + 1{\cdot}403 \log p$	4
$-\ 0{\cdot}0314 = \log a + 1{\cdot}427 \log p$	5
$-\ 0{\cdot}0339 = \log a + 1{\cdot}453 \log p$	6
$-\ 0{\cdot}0365 = \log a + 1{\cdot}480 \log p$	7
$-\ 0{\cdot}0392 = \log a + 1{\cdot}508 \log p$	9
$-\ 0{\cdot}0420 = \log a + 1{\cdot}538 \log p$	9
$-\ 0{\cdot}0449 = \log a + 1{\cdot}570 \log p$	8
$-\ 0{\cdot}0479 = \log a + 1{\cdot}603 \log p$	8
$-\ 0{\cdot}0510 = \log a + 1{\cdot}638 \log p$	6
$-\ 0{\cdot}0542 = \log a + 1{\cdot}676 \log p$	$-\ 0{\cdot}0003$
$-\ 0{\cdot}0575 = \log a + 1{\cdot}715 \log p$	$0{\cdot}0000$
$-\ 0{\cdot}0609 = \log a + 1{\cdot}757 \log p$	$+\ 0{\cdot}0004$
$-\ 0{\cdot}0645 = \log a + 1{\cdot}802 \log p$	10
$-\ 0{\cdot}0683 = \log a + 1{\cdot}849 \log p$	15
$-\ 0{\cdot}0725 = \log a + 1{\cdot}900 \log p$	20
$-\ 0{\cdot}0771 = \log a + 1{\cdot}953 \log p$	23
$-\ 0{\cdot}0823 = \log a + 2{\cdot}010 \log p$	24
$-\ 0{\cdot}0881 = \log a + 2{\cdot}072 \log p$	$+\ 0{\cdot}0023$

	$t-c.$
$-0{\cdot}0945=\log a+2{\cdot}137\log p$	$+0{\cdot}00019$
$-0{\cdot}1014=\log a+2{\cdot}207\log p$	15
$-0{\cdot}1088=\log a+2{\cdot}283\log p$	11
$-0{\cdot}1167=\log a+2{\cdot}364\log p$	7
$-0{\cdot}1254=\log a+2{\cdot}452\log p$	$+0{\cdot}0002$
$-0{\cdot}1348=\log a+2{\cdot}547\log p$	$-0{\cdot}0005$
$-0{\cdot}1449=\log a+2{\cdot}650\log p$	11
$-0{\cdot}1557=\log a+2{\cdot}762\log p$	15
$-0{\cdot}1673=\log a+2{\cdot}884\log p$	18
$-0{\cdot}1797=\log a+3{\cdot}017\log p$	20
$-0{\cdot}1930=\log a+3{\cdot}163\log p$	18
$-0{\cdot}2074=\log a+3{\cdot}324\log p$	13
$-0{\cdot}2232=\log a+3{\cdot}501\log p$	8
$-0{\cdot}2407=\log a+3{\cdot}697\log p$	$-0{\cdot}0001$
$-0{\cdot}2603=\log a+3{\cdot}915\log p$	$+0{\cdot}0004$
$-0{\cdot}2823=\log a+4{\cdot}157\log p$	8
$-0{\cdot}3069=\log a+4{\cdot}428\log p$	$+0{\cdot}0012;$

whence

$$51{\cdot}00\log a+101{\cdot}7900\log p-4{\cdot}2542=0,$$

$$101{\cdot}79\log a+240{\cdot}8824\log p-11{\cdot}9755=0;$$

whence

$$\log a=0{\cdot}10096;\ \log p=9{\cdot}90762-10.$$

If these values of $\log a$ and $\log p$ are substituted in the above fifty-one equations, the equations will be found to be satisfied, excepting the $t-c$ (table – calculation) given on the right of the page.

The smallness of these differences naturally leads us to regard the formula as trustworthy for those circumstances under which it has hitherto been impossible to procure observations, and even for those cases where they are altogether beyond our reach.

For taking the formula (1),

$$t=ap^{\varepsilon},$$

we have only to put $\varepsilon=1$ in order to get

$$t=ap,$$

or the zenith-effect of the moon's heat; and further, by taking the extreme case $\varepsilon=0$, we have

$$t=a,$$

or the heat-effect supposing the atmosphere to be removed altogether*.

---

* Taking the moon's maximum zenith heat-effect at the earth's surface at 407·3 (p. 606), we have 513·9 as the maximum before her rays enter our atmosphere.

It will be remembered that the value $\phi z=0\cdot0046$ for $z=29°$ was obtained by comparison with SEIDEL's results, based on the comparison of observations of the light of stars near the zenith with that of others at various altitudes.

Formula (1) now enables us to find this quantity independently of SEIDEL's results; for since ϕz is the logarithmic factor for reducing to the zenith it must become zero for $s=1$, or we have the new condition

$$\log a+\log p=0\ ;$$

it is, however, 0·00858, which must be added to all the values of ϕz and subtracted from $\log a$ in order to fulfil the above condition.

Simultaneous Observations of the Moon's Heat and Light during the Eclipse of November 14th, 1872.

During the partial eclipse of the moon of November 14th, 1872, an attempt was made to ascertain whether or not the lunar surface required an appreciable time to acquire the temperature due to the action of the sun's light shining on it at the moment.

Obviously a total eclipse would be a favourable time for determining this point (at least for heat which has penetrated to a small depth only), as the transition from light to darkness is so much more rapid than that caused by the moon's rotation on her axis; but owing to the smallness of the eclipse (there being little more obscuration than that due to the penumbra alone), the considerable decrease of the moon's altitude towards the close of the eclipse, and still more to the uncertainty of the weather (which allowed us only a few glimpses now and again of the moon), the results only go so far as to show that the heat was diminished during the eclipse in a rather greater proportion than the light. The minimum for both heat and light occurred at or very near the middle of the eclipse.

The following Tables, in which the columns correspond respectively to those with the same heading in the Tables already given, contain full particulars of the observations and their reductions.

The moon's light was measured with a ZÖLLNER's photometer, with which, as is well known, the total light of the observed body is, *cæteris paribus*, proportional to the square of the sine of the reading of the intensity-circle. This reading is given in column I. (see next page). This being borne in mind, the meaning of the other columns will be readily understood.

Observations of the Moon's Heat, Nov. 14th, 1872.

Sidereal time.	Mean deviation (G).	The Moon's			log (g).	log (σ).	ϕz.	Zenith-mean (z).
		ε.	Zenith-distance.	Apparent semidiameter.				
h m		° ′	°	′ ″				
6 15	479·0	−2 7	50·2	15 40·0	9·9960	0·9970	0·0426	520·0
7 47	264·7	−1 40	62·4	15 37·5	9·9977	0·9994	0·0906	323·9
8 32	186·4	±1 34	68·9	15 35·7	9·9994	0·0010	0·1439	259·8
8 45	182·5	±1 34	70·8	15 35·2	9·9994	0·0014	0·1649	267·3
9 6	198·6	+1 32	73·9	15 34·4	9·9993	0·0022	0·2059	320·2

The moon's tabular semidiameter . . . =15′ 36″·6

The moon's adopted apparent semidiameter =15 30·0

Observations of the Moon's light, November 14th, 1872.

Sidereal time.	I.	Log sin² I.	Log. corr. (σ).	Zen.-dist.	Moon's app. semidiameter.	ϕz.	Moon's light.
h m	°			°	′ ″		
6 14½	49·5	9·762	9·997	50·1	15 40·0	·045	0·6368
6 18½	47·5	9·735	9·997	50·6	15 40·0	·047	0·6012
7 46½	34·65	9·510	0·000	62·4	15 37·3	·116	0·4227
7 50	32·15	9·452	0·000	62·9	15 37·2	·120	0·3733
8 28½	31·0	9·424	0·001	68·5	15 35·8	·175	0·3981
8 33½	29·05	9·372	0·001	69·2	15 35·6	·182	0·3589
8 37½	29·2	9·377	0·001	69·8	15 35·5	·189	0·3690
*8 41½	23·95	9·217	0·001	70·3	15 35·3	·195	[0·2588]
8 45½	29·5	9·385	0·001	70·9	15 35·2	·203	0·3882
8 49½	31·4	9·434	0·001	71·4	15 35·0	·210	0·4416
9 8½	29·35	9·380	0·002	74·2	15 34·2	·253	0·4295
9 12½	27·6	9·332	0·002	74·8	15 34·2	·264	0·3963

Interpolating the light-observations and multiplying them by the common factor 764·9 to reduce them to the same scale as the heat-observations, the following comparison of the moon's heat and light is arrived at.

Comparison of the Moon's Heat and Light.

Sidereal time from middle of eclipse.	Moon's heat.	Moon's light.	$l-h$.
h m			
−2 11	520·0	477·6	−42·4
−0 39	323·9	309·0	−14·9
+0 6	259·8	295·2	+35·4
+0 19	267·3	299·3	+32·0
+0 40	320·2	309·8	−10·4

It may be well to add that although the thermopiles used on this day were the same as for the rest of the experiments, they had been remounted in the early summer, by which their sensitiveness was considerably increased. The allowance for the extinction of the moon's heat in the atmosphere was made in accordance with the Table deduced in the earlier part of this paper, while that for the moon's light was taken from Professor SEIDEL'S Table.

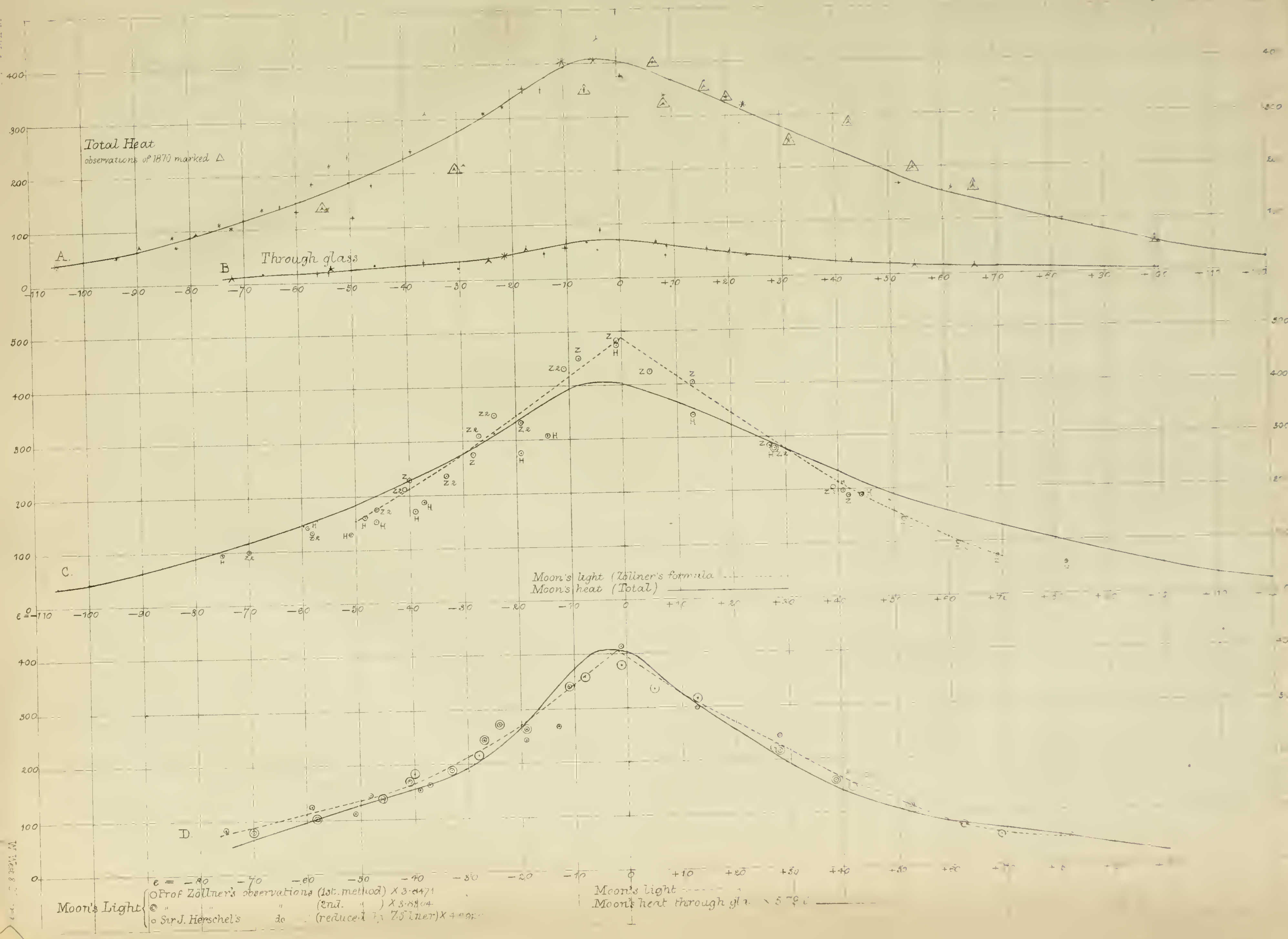
Comparison of the Phase-Curve for Heat as given in this paper with that for Light deduced by Professor ZÖLLNER *from his and Sir* JOHN HERSCHEL'S *observations.*

A diagram (Plate XLVIII., Curve C) accompanies this paper, on which is laid down the heat-curve and the determinations for the moon's light, those marked Z and Z2 derived from observations made by Professor ZÖLLNER by his first and second methods taken from the Table at p. 102 of the 'Photometrische Untersuchungen,' and those marked H derived from Sir JOHN HERSCHEL'S observations taken from plate iv. of that work.

---

* Some mistake in reading the intensity-circle; observation rejected.

Phil. Trans. MDCCCLXXIII. Plate XLVIII.



W. West & Co.

LIBR
OF TH
UNIVERSITY OF ILLINOIS

Four determinations made by Professor ZÖLLNER after his diagram was engraved are here given, and two errors pointed out by him* in the elongations of two of Sir JOHN HERSCHEL's observations (caused by errors in the 'Cape Observations') have been rectified. The dotted line is Professor ZÖLLNER's calculated curve, the ordinates of which have been increased in the ratio of 4·880 to 1, so as to make it agree as closely as possible with the heat-curve†.

On inspecting the diagram, it is at once apparent that the increase of the moon's light in approaching the full moon is more rapid than that of her heat, so much so that ZÖLLNER resorted to a cusped curve for its representation. The introduction of the additional observations, however, three of which are upper ones in elongations −27°, −24°, and −11°, would not only seem to indicate a necessity for rounding off the maximum of the light-curve, but also for placing it slightly before full moon, and thus making it agree with the heat-curve in this remarkable feature.

Some uncertainty appears to arise on account of the employment by ZÖLLNER of a photometer in which, when used on the moon, the light has to traverse a system of Nicol prisms; but it does not appear clear in what azimuth the system was turned during each observation, and consequently it is not known whether the correction due to this cause would diminish the departure of the heat- from the light-curve, or the reverse‡.

Attempt to compare the Moon's Radiant Heat with that from a terrestrial source.

The effect of the moon's heat has hitherto been expressed in this paper on a purely arbitrary scale, namely by the differences of the readings of one and the same galvanometer under certain conditions of adjustment, when acted on by the electric currents generated by the moon's heat, which, falling on the large mirror of the 3-foot telescope, is concentrated by concave mirrors of short focal length alternately on each of a given pair of thermopiles. It was therefore desirable to compare the effect thus produced by the moon's heat with that of a given terrestrial source (say, a blackened tin vessel) acting under circumstances as nearly as possible similar to those in the case of the moon. The great focal length of the telescope (27 feet) altogether precluded the use of the whole instrument for this purpose, so the condensing-mirrors with the thermopiles were detached from the telescope, and each separate pile was exposed to the alternate action of two circular surfaces of blackened tin backed by water of different temperatures, these surfaces being alternately exposed for the interval of a minute through a circular aperture in a fixed wooden screen.

---

* Photometrische Untersuchungen, p. 175, note.

† In accordance with the heading of the Table (Phot. Unt. p. 198) the curve is kept within the limits of 50° before and 70° after full moon.

‡ Taking the extreme case, where the plane in which the sun, moon, and earth, and therefore the plane in which the moon's light is polarized, is parallel to the plane of reflection of the transparent plate of parallel glass in the photometer, the system of Nicols being supposed to be set with the principal axis parallel to this plane, the phase-curve obtained would differ from the heat-curve by only about two thirds the present amount. Were the system of Nicols moved round through 90°, the correction to be applied to the curve would be in the other direction.

It has been assumed that the ratio of the two components of natural light after passing through the plate of glass is 0·84 to 1·00 at 45° incidence, and the corresponding ratio for moonlight 0·83 to 1·00 (probably too high an estimate of the mean polarization of the moon's light), at quadrature the maximum polarization occurring at about 77° elongation. The ratio of intensities found in the two cases would thus be the same at about 85° from full moon, and their ratio 0·84 to 1·00 at full moon. Sir J. HERSCHEL employed a photometer which appears to be free from this source of error.

I cannot find that any one has devoted much attention to the subject of the polarization of light from the moon except ARAGO and Father SECCHI. The former states that the maximum polarization occurs at or near quadrature, but gives no estimate of its amount. Our experiments in this direction are not as accordant as might be wished, and for the present do not appear worth publishing.

It may, however, be well that any who happen to be working at Photometry should have their attention in the mean time called to this possible source of error.

In this way, by varying the temperature of the water, a considerable range of readings of the galvanometer was obtained; and these being compared, by means of an empirical formula it was easy to calculate the reading for any given temperatures of the tins.

In this way, by taking into account the moon's apparent semidiameter, the effective area and reflective power of the 3-foot speculum, and the action of the *two* piles on the one hand, and the distance and radius of the circular aperture, the effective area of the condensing-mirror, and the *one* pile on the other, the temperature of the tin vessel necessary to produce an effect equal to that of the full moon, when acting under similar circumstances, could be at once calculated.

In the case of the moon-observations we have the following particulars:—

in.
Full area of speculum . . . . . . =973·12
Deduct for direct obstruction . . . =116·80
856·32

The assumed reflective power of the speculum . . . . =0·5325
Proportion of the cone of rays not intercepted by pile and holder =0·90064
Hence the 3-foot speculum may be replaced by one of perfect reflective power whose area . . . . =410·7 sq. in.
Moon's mean apparent semidiameter . . . . =15′·557

If we take 1′ as the unit,

$$\text{the moon's area}=\pi\times 15{\cdot}557^2,$$

and the source of lunar radiation for a unit of excess of temperature

$$=\pi\,.\,(15{\cdot}557)^2\times 410{\cdot}7=\mathrm{M}.$$

Again, the distance of the hot tin from the condensing-mirrors was 111 inches, its radius 6 inches, and the unobstructed area of the condensing-mirror 8·597 inches, therefore source of heat for comparison $=\pi(0{\cdot}054054\times 3437{\cdot}75)^2\times 8{\cdot}597=\mathrm{T}$; hence

$$\frac{\mathrm{T}}{2\mathrm{M}}=1{\cdot}4933.$$

That is, under the circumstances stated above, a difference of temperature of the blackened tins acting alternately on *one* pile produces 1·4933 times the effect that the same excess of temperature of the area occupied by the moon's disk above that of an equal area of the neighbouring sky (assumed of the same temperature as the colder tin) would do acting on the *two* piles in their position in the telescope.

It has been shown (p. 618, note) that the moon at full, or, more strictly speaking, at the time of its maximum heat, before its rays traverse our atmosphere, would produce an effect on the galvanometer of 513·9 parts of the scale; therefore the tin at the same excess of temperature (the radiating powers of the two surfaces being assumed equal) would give 513·9 × 1·4933 = 767·4 parts.

Therefore, employing Dulong and Petit's formula for the velocity of cooling*,

$$V=ma^{\theta}(a^{t}-1)$$

(where θ is the temperature in degrees Centigrade of the colder tin, $t+\theta$ that of the hotter one, a a constant $=1·0077$, V the mean difference of consecutive pairs of readings of the galvanometer, and m a constant deduced from experiments with the tins $=558·0$†), a mean value of $\theta=45°$ Fahr. (7°·22 Cent.) will give $V=767·4$ when $t=197°·5$ Fahr. (109°·7 Cent.)‡.

This result, it will be observed, differs much from a rough estimation of the value of the scale-readings given at the conclusion of a former communication§. Probably this may be caused principally by neglect in distinguishing between the effect of one pile and of both piles; in other words, omitting a factor 2 from the former calculation, the

---

[*] Annales de Chim. et de Phys. t. vii. This formula is, strictly speaking, only applicable to a radiating body *in vacuo*; but for the comparatively moderate temperatures here dealt with it is perhaps as correct as any other.

[†] These experiments were made on March 25th and 26th, 1872, and are as follows, where V is the mean of 10 consecutive differences:—

	θ (Cent.).	t.	V obs.	V calc.	C−O.	
Pile A.	5°·67	24°·44	110·4	113·9	+3·5	
	6·06	21·83	100·7	100·9	+0·2	
	7·11	40·11	198·8	200·9	+2·1	$m=534·3$
	7·50	34·39	172·3	169·0	−3·3	
	7·89	29·78	145·7	144·1	−1·6	
	8·33	24·39	116·4	115·9	−0·5	
Pile B.	5·78	23·11	110·4	116·7	+6·3	
	6·17	20·50	95·6	102·8	+7·2	
	6·72	43·22	241·4	238·0	−3·4	
	7·33	36·95	202·7	199·4	−3·3	$m=581·7$
	7·72	32·22	170·2	171·1	+0·9	
	8·00	28·17	148·1	147·5	−0·6	
	8·28	26·22	137·1	136·6	−0·5	

[‡] If Newton's law ($V=Ct$) be employed, the corresponding excess of temperature of the tin would come ou 152°·2 Cent. = 274° Fahr.

[§] Proceedings of the Royal Society, No. 112 (1869), p. 443.

details of which have not been preserved. Although the result now given has been worked out with every care, it must still be considered simply an attempt to connect the readings of the galvanometer with a constant known source of heat; and we must admit that the problem of the determination of the lunar temperature is nearly as far removed as ever from our grasp. The formula we have made use of is admitted to be a purely empirical one, based on experiments made within very limited ranges of temperature, within which it appears to agree more closely with the observed law than NEWTON'S more simple formula. Nevertheless we can obviously feel no assurance that it is generally true, nor indeed can we employ it, like NEWTON'S, to determine the excess of the temperature of the hotter over that of the cooler body, without knowing one or other of the two temperatures.

I feel that I should not conclude this paper without bearing testimony to the energy and perseverance with which my assistant, Dr. RALPH COPELAND, has conducted the observations which form the subject of the greater part of it, as also to the great care and the ability with which he has worked out the reductions. I had hoped to have sent in this paper before the close of last Session; but the greater completeness which is the result of the delay, as well as the fact that the exceptionally unpropitious state of the weather would have prevented our profiting, in a new series of observations by any suggestions which might have come to us, have removed all cause for regretting this. One thing I should have much wished to have added to this investigation had there been any reasonable prospect of doing so without considerably more delay—namely, a more satisfactory determination of the value of the scale, by means of a comparison of the deviations due to solar with those due to lunar radiation, than that given in a former communication based on observations made with an uncertain sky and of only two or three hours' duration.

APPENDIX.

Received May 7, 1873.

Since the foregoing was written an explanation has suggested itself for the very considerable divergence (more than could fairly be ascribed to errors of observation) of our heat-curve from Professor ZÖLLNER'S light-curve for change of phase, which will at the same time account for the increase of the percentage of heat transmitted by glass towards the time of full moon.

Were it not for the negative result obtained with the thermopile on March 24th, 1871*, the latter fact might perhaps have been attributed to a constant amount of heat emitted from the interior of the moon; but now this explanation is no longer admissible.

On referring to the Table at page 615 of the foregoing paper, it will be seen that the percentage of heat transmitted by glass increases gradually from each side to a maximum at or near the time of full moon; consequently the phase-curve for "heat through glass" will rise more rapidly towards full moon than the total heat-curve, and should therefore diverge less from Zöllner's than the total heat-curve, when the ordinates are increased by a suitable factor.

---

* See page 589, note.

This comparison has accordingly been made. The ordinates of the curve B (Plate XLVIII.) have been multiplied by 5·7916, to make the curve correspond in average height with curve A (Plate XLVIII.); and, with the same object, Zöllner's photometric determinations obtained with two different photometers and those by Sir John Herschel with the prism photometer were multiplied respectively by the following factors*:—

Zöllner's 1st method	3·8471
„ 2nd (or improved) method	3·8304
Herschel's	4·2920

Applying these factors to the numbers given at page 102 of the 'Photometrische Untersuchungen' (for Zöllner's observations), and to the quantities taken from plate iv. of that work for Herschel's results, the following numbers were obtained:—

Professor Zöllner; 1st method.

ε.	Moon's light.	ε.	Moon's light.
−40°	181·2	+13°	317·7
−28	217·1	+27	222·7
− 8	354·7	+42	146·7
− 1	379·3	+69	56·1
+ 5	335·5		

Professor Zöllner; 2nd method.

ε.	Moon's light.	ε.	Moon's light.
−70°	77·8	−19°	262·0
−58	103·9	−11	339·9
−46	138·3	+28	218·3
−41	168·2	+39	159·7
−33	187·1	+52	111·5
−27	243·1	+62	78·1
−24	273·4		

---

* The necessity for applying different factors to render comparable groups of observations already similarly treated by Zöllner, arises from the fact that Zöllner, since he constructed his diagram, has added four observations by his second method, and has discovered two errors of 10° each in the elongation of the moon as given in the 'Cape Observations.'

Sir John Herschel.

ε.	Moon's light.
−75°	81·6
−59	127·0
−51	112·9
−48	144·6
−46	134·4
−39	151·1
−37	165·3
−19	243·0
−13°	269·6
− 1	417·3
+13	300·4
+28	244·6
+41	171·7
+44	166·2
+82	52·4

Then tracing with a perfectly unbiassed mind the curve given in Plate XLVIII. (Curve D), and not until afterwards superposing the curve of "heat through glass," treated as already stated, there was found to be a fair agreement between the two curves.

For the luminous rays, then, from the moon, the results obtained with the eye aided by the photometer and those derived from the indications of the thermopile are as nearly identical as could be expected; and it seems just to seek for the explanation of the far greater divergence (see Plate XLVIII., Curve C), under more favourable circumstances of observation, of the "total heat-curve" in a real difference between the laws which govern the emission of heat and light from the lunar surface.

Let us for the moment assume with Zöllner that the moon's surface is covered with angular ridges, whose sides are planes of, say, 52° inclination, and whose direction is perpendicular to the plane in which the earth, sun, and moon lie. The sun's light will then in many parts shine on one side only of each of these ridges, which will reflect or diffuse the incident light diminished by the amount absorbed. Let $1-\mu=$ quantity absorbed, $\mu=$ that emitted.

Some of the latter will strike the shaded sides of the ridges, but of this $1-\mu$ will be absorbed and only μ emitted. With the heat, however, this will not be the case. If the moon's temperature be assumed from moment to moment practically constant, the *whole* of the heat which falls on her surface must necessarily leave it again; whereas for every unit of light and heat which falls on the surface, of the former only μ leaves it after one reflection, μ^2 after two reflections, μ^3 after three reflections, and so on. Therefore the proportion of heat emitted by the shadows will be, as compared with the light coming from those same parts, $\frac{1}{\mu}$ times greater than what comes from the parts in direct sunlight; the heat emitted in directions removed some distance from the sun will be larger compared with that thrown back more towards the sun, and the greater flatness of the heat-curve and the increase of percentage of heat transmitted by glass at or near full moon are at once explained.

The complete solution of the question would probably be complicated, and, owing to the very unequal distribution of mountain and plain, perhaps unprofitable, even if we possessed fuller data than we at present have on which to base our calculations.

A further, but probably a less important, cause for the divergence of the heat- and light-curves lies in the fact that the moon's surface to a certain extent "regularly reflects" as well as diffuses light and heat.

Let R, R′ be respectively the light and heat regularly reflected.
  D, D′ be respectively the light and heat regularly diffused, unchanged in refrangibility.
  E, E′ be respectively the light and heat regularly absorbed and afterwards emitted.
  F, F′ be respectively the light and heat regularly radiated after more than one reflection.

As long as $\frac{D+E+F}{D'+E'+F'}=\frac{R}{R'}$ the two curves will be identical, even though R and R′ be a different function of the elongation from D+E+F and D′+E′+F′. But if this relation does not hold, which will be the case if $\frac{R}{R'}=\frac{D}{D'}$ for $F'<F$ and $E'=0$, then the phase-curve for R, R′ will govern the resulting curve for total light more than it will do that for total heat.

XVII. *On a new Genus of Amphipod Crustaceans. By* RUDOLPH VON WILLEMÖES-SUHM, *Ph.D., Naturalist to the 'Challenger' Exploring-Expedition. Communicated by* Dr. WYVILLE THOMSON.

Received February 27,—Read March 6, 1873.

LEAVING Gibraltar on the 26th of January, 1873, H.M.S. 'Challenger' proceeded in a south-westerly direction, and on the 28th the trawl was sent down, in lat. 35° 47′, long. 8° 23′, to a depth of 1090 fathoms, the temperature of the surface being 15°·55 C., and that of the bottom 2°·66 C. The haul was an uncommonly rich one; for, besides three species of fishes and many very interesting Echinoderms, a species of *Euplectella* was brought up and a large transparent animal, which we at first thought might be the larva of one of the higher Crustaceans.

Two enormous faceted eyes occupying the whole upper part of the head, and the presence of what seemed clearly to be an ovary, negatived, however, that supposition; and at Professor WYVILLE THOMSON's request I made a closer examination of this animal, which was evidently of great interest in many respects.

The specimen is almost entirely transparent. Its length is 84 millims. and its greatest breadth 21 millims. The body consists of three parts:—1. The *head*, with one pair of antennæ in front, two contiguous faceted eyes occupying the whole of its upper surface, and the mouth situated at the posterior part of the under surface. 2. The *thoracic region*, composed of six segments, bearing two pairs of maxillipeds, five pairs of ambulatory legs, and three pairs of branchiæ. The second pair of maxillipeds and the first pair of ambulatory legs are on the second thoracic segment, which, as we shall see hereafter, may probably be formed by the fusion of two segments. We also remark the vulva on the under surface of the first segment. 3. The *abdomen*, which consists of five segments, three bearing pairs of *pedes spurii*, and the fourth and fifth the caudal appendages and the anus. An elevated line running along the dorsal aspect of the thoracic and abdominal regions divides them longitudinally into a right and a left half.

THE HEAD.—The upper surface of the head is entirely occupied by two contiguous faceted eyes, which are separated from one another by a mesial line, 20 millims. in length (Plate XLIX. figs. 2 & 3). Each eye is 13 millims. in width, and its anterior and lateral borders are limited by a slightly coloured band, which will be referred to when considering the structure of the eyes. The posterior border nearly corresponds with the posterior border of the head, which arches gently over to the first segment of the thoracic region. The anterior border of the head is transverse and nearly straight, running out at either side into a spine, which is the first and largest of a series of twelve spines bordering the outer edge of the head-shield. The mouth (Plate XLIX. fig. 1, *o*) is a very small opening on a round papilla placed near the posterior edge of the lower surface of the head. It is covered by a pair of rudimentary maxillæ, with a sort of labium between them, and by two pairs of maxillipeds (Plate XLIX. fig. 1, *mx*). A groove, the borders of which are adorned by series of one larger and five smaller teeth, runs backwards to the mouth along the middle line of the lower surface of the head. Fig. 3 gives a lateral view of the under surface, which is more easily understood from a figure than from the description. At the frontal border, separated by a distance of about 7 millims., there are two antennæ 26 millims. long. The antennæ consist of two elements, of which the proximal is longer than the distal, which is enlarged at the end, and bears a very small recurved claw.

THE THORACIC REGION consists of six segments. The first of these bears the smaller pair of maxillipeds, and shows on its inferior surface an elevation, which is the genital papilla. The second segment is wider than the first, and bears two pairs of appendages—the longer maxillipeds and the first pair of ambulatory legs, which are more slender than the other four pairs, and have the proximal joint not so strongly denticulated; they are also inserted a little within the other four pairs, and they were held by the animal (which was still living when brought up) in the characteristic position of the accessory legs of the pycnogonid *Nymphon*. The eggs, which in this case are not held by the two rudimentary lamellæ near the vulva, were attached to these legs. The next four segments of the thoracic region bear each one pair of ambulatory legs, making, along with the pair on the second thoracic segment, five pairs in all. Of these the third pair is the longest; this is followed in length by the fourth, then comes the second, then the fifth, and finally the first. The length of the longest limb is 69 millims. The legs consist of four joints, showing denticulations and hairs. At the point of attachment of the proximal joint to the body no coxa can be distinguished. The leg is inserted into the thoracic segment, in the same manner as in *Phronima*. In the limbs of the third, fourth, and fifth pairs the proximal joint is terminated distally by a large spine. The second joint is very small in the limbs of the first pair, and still smaller in those of the fifth. In the limbs of the fifth pair the third joint is also remarkable, as it bears at its distal end a large tuft of straight hairs; and the fourth is more enlarged than the corresponding joint of the other limbs, and terminates in a stronger and more recurved claw. In *Phronima* the fifth pair of ambulatory legs, which corresponds with the third pair in the present form, presents the same modification. The enlarged distal terminations of the limbs and of the antennæ are not, like the remaining part of the appendages, transparent, but are of a milk-white colour, produced, I believe, by glands in their interior analogous to the glands in the enlarged claw of *Phronima*. To the bases of the second, third, and fourth pairs of legs three pairs of gills are attached.

THE ABDOMEN consists, as in *Phronima*, of five segments, the first three of which bear pairs of abdominal feet, consisting of a quadrate basal joint, to which are attached two feathered appendages. These are followed by two segments, to each of which are attached a pair of appendages, the four forming together the tail. Each of these appendages is bifurcate with a sharp and a rounded point. The rounded termination is milk-white, and is separated from the main piece of the appendage by an articulation. The anus is situated at the end of the last segment.

The Muscular System.—The animal is so transparent that all the main muscles are clearly visible; but they do not seem to present any thing very remarkable, with the exception of those of the thoracic legs, which are only very weakly developed. From this I suppose that the movements of the animal are not very rapid when it is obliged to walk over the sea-bottom. It may be, however, that, like *Phronima*, it makes but little use of these legs, and swims by aid of the abdominal feet only; these also are very small in relation to the size of the body.

The Nervous System.—The transparency of the body makes it possible likewise to distinguish clearly the cephalic ganglion and the ventral chain, consisting of five thoracic and three abdominal ganglia (Plate XLIX. fig. 1). The cephalic ganglion is situated in the anterior part of the head, more on the dorsal than on the ventral side; it is 3·50 millims. in width, and is horseshoe-shaped with pointed ends. From the middle of its anterior margin two large nerves run straight to the end of the antennæ, while from the opposite side two commissural cords run backwards, traversing the head and, after having encircled the mouth, uniting with the first thoracic ganglion. The nerves passing from the sides of the cephalic ganglion are all employed as ocular nerves to supply the huge compound eyes. Those of the anterior end are better seen, as they go to the anterior part of the eyes, while those of the posterior end seem to go to the posterior parts.

The first thoracic ganglion is seated just underneath the ovary in the second segment, and sends out the nerves for the mouth and for the genital organs. The two cords then separate till they are united again in the third segment in the second ganglion; thence they run backwards in a single chain and form a ganglion in each of the subsequent segments, sending nerves to the legs. Altogether we find five thoracic ganglia for six segments, and in the abdomen three ganglia for five segments. The last ganglion of the abdomen is more slender than the preceding ones, and seems to send out nerves in different directions, especially to the anus and caudal appendages. In *Phronima* there are ten pairs of ganglia, five of which, as in the present case, are thoracic and five abdominal.

The Eyes are contiguous, the line separating them being, however, clearly visible: the length of this line is 20 millims. The eyes thus occupy a rectangular space, the outer edges of which are separated from the spiny borders of the head-shield by a space 6 millims. in width. At the front of the head there is a space of 3 millims. between their anterior borders and the line into which the two antennæ are inserted.

Along the sides of the eyes there is a brownish line produced by elongated chitinous appendages, 0·140 millim. long (Plate L. fig. 8), attached irregularly to the borders of the cornea. These appendages are hollow tubes pointed and closed at the top, and flattened and slightly denticulated at the base. The cornea of the eye is faceted externally, the facets being hexagonal (Plate L. fig. 7). Beneath the facets we find very elegant slender crystalline bodies, 0·840 millim. long, and at the top 0·147 millim. broad (Plate L. figs. 9, 9 *a*). I have figured two pairs of these, as they are always united together by their slender ends, the point of union being shown at fig. 9 *a*. In their upper part a granulation is to be seen, giving them a slightly brownish colour; and in their tapering extremities there are some clear vesicles, which have some resemblance to the varicosities of a nerve-fibre. The nerve-rods which are present in *Phronima* are absent in this form, and there is no pigment.

It is impossible to say whether organs of hearing or of touch exist, as it was not practicable to dissect the single specimen we procured in order to examine the different parts under the microscope.

THE ORGANS OF DIGESTION AND THE PARTS OF THE MOUTH.—The opening of the mouth (Plate L. fig. 6, *o*) is oval, and is situated on the top of an elevation (Plate L. fig. 6, A) at the base of the head. It is usually closed by a pair of very small denticulated maxillæ (fig. 6, *ma*), and between them a labium (fig. 6, *lab*) in the form of a small denticulated plate. Other maxillæ are entirely wanting; they are physiologically represented by two pairs of maxillipeds, which must be regarded morphologically as two pairs of ambulatory legs transformed for that purpose. Their relations become apparent on comparison with *Phronima*. These maxillipeds (Plate XLIX. fig. 1, *mx*) consist of two joints, and are terminated by a pair of claws. The external margin of the second joint is denticulated. The first pair of maxillipeds is attached to the first segment of the thorax, and the second larger pair to the second segment, to which is also attached the first pair of ambulatory legs. I therefore think that this larger second segment has arisen from the fusion of two segments.

The small mouth leads into a large slightly yellowish stomach, through a recurved œsophageal passage, in which there seems to be a chitinous layer, as a dark spot is to be seen there from the outside. The walls of the stomach (Plate XLIX. fig. 3, *cœ*) are striated and probably muscular. The stomach appears to be cæcal, and the particles of food brought into it must return in order to get into the intestinal tube, which opens from the œsophagus and runs as a thick-walled tube over the right side of the ovary (fig. 3, *in*). Its walls then become thinner and nearly transparent, so that only its reddish contents showed me the remainder of the tube running straight to the anus (figs. 1 & 2, *as*), to which muscular fibres, forming a sort of *constrictor ani*, are attached on both sides.

This configuration of the digestive system is in many respects similar to that in *Phronima*; the external parts of the mouth, however, bear but little resemblance to those in that genus. In *Phronima* there are one pair of mandibles, two pairs of maxillæ, and a labium; while of these we have here only the labium and one pair of maxillæ. In *Phronima* the two first pairs of ambulatory legs have no relations to the mouth as they have in this case.

The dark spot which we have pointed out in the œsophagus appears to answer to what Claus calls the "dental plates" in *Phronima*; and the cæcal appendage which he describes in that animal has, in the present species, assumed so large dimensions as to have replaced the stomach, which does not exist morphologically, but is physiologically represented by the cæcum.

Circulation and Respiration.—While the animal was alive I did not succeed in seeing the heart. I only saw it when it had been put into weak spirit; and under the same treatment I also saw the nervous system much better than before. The heart is an elongated tube extending from the second to the fifth segment (Plate XLIX. fig. 3, *c*). Probably there are three openings in it as in *Phronima*, one in each segment; but of these nothing could be made out.

The respiratory organs consist of three pairs of small transparent sac-like gills at the bases of the second, third, and fourth pairs of feet (Plate XLIX. fig. 1, *br*). They are in form and number nearly the same as in *Phronima*. The water is driven over them by the action of the three pairs of abdominal feet.

Genital Organs.—The single specimen taken is a female. There is a large ovary, distinguished by its rose-colour, occupying the middle portion of the first body-segment (Plate XLIX. fig. 3, *ov*). I suspect that it consists of two ovaries lying close together, and having two excretory ducts leading to the genital papilla; but it is impossible to ascertain this without mutilating the specimen. The genital papilla is an elevation in the centre of the ventral surface of the first thoracic segment between the two limbs, which, as I have already mentioned, are destined to bear the eggs at their base, as in the females of *Nymphon*. The colour of the papilla is rose, with scattered scarlet points produced by small spines on the surface of the carapace. In the centre of the genital papilla there is a large spine (Plate L. fig. 6, *d*) with a groove leading into a depression (*c*), in which I believe are seated the apertures of the ovarian ducts. This pit is protected by two soft appendages (Plate L. fig. 6, *l*), answering to the valves which are to be found in most female Amphipods, and in which they keep their eggs. In the present species, however, they are only rudimentary, and they do not seem to be used for that purpose, as I found the eggs attached to the bases of the first pair of ambulatory legs.

Eggs and Development.—The eggs which I found adhering to the legs had a diameter of 0·7 millim., and were provided with an unsculptured chorion. They contained embryos in different stages of development. Unfortunately I discovered this only after the animal had been for a night in weak spirit, in which it had been placed for fear it should suffer decomposition.

The main point with regard to its embryology could, however, still be settled—namely, that there is no metamorphosis, and that the antennæ, the five pairs of thoracic, and the abdominal legs are already to be seen in the embryo. Figs. 4 and 5 of Plate L. give lateral and dorsal views of an embryo, showing the five ambulatory legs. Embryos in the stages which showed the antennæ and the abdominal legs were not in a sufficiently good state of preservation for figuring. All the eggs seemed, as might have been expected, to be in nearly the same stage of development, and I could not determine whether the spherical organ ("kugelförmiges Organ" of the Germans) makes its appearance or not.

SYSTEMATIC POSITION AND AFFINITIES.—We have already pointed out so many relations between the Crustacean described and *Phronima*, that no room is left for doubt that it is an Amphipod, although an aberrant one. We must now consider the characters in which the new genus differs from *Phronima* as well as from the Amphipods in general, and the position which must be assigned to it in the system of classification. I have only a very small part of the literature of the Amphipoda to refer to; but the form and the anatomical structure of this genus is so remarkable, that I think, had it been previously described in detail, either Professor WYVILLE THOMSON or I must have seen a figure of it. As this is not the case, I venture to introduce it to science with the following generic characters under the name of

THAUMOPS, gen. nov.

Caput oblongum, inflatum, oculis maximis superiorem capitis partem tegentibus. Segmenta thoracica 6, abdominalia 5. Antennarum in feminis par unum, maxillarum par unum, pedum paria duo minima maxillarum locum tenentia. Mandibulæ nullæ. Pedes thoracici 5, abdominales 3 in quoque latere. Appendices caudales 4. Gangliorum pectoralium paria 5, abdominalium 3.

Thaumops pellucida, sp. nov.

Corpus longitudine 84 mm., latitudine 21 mm., pellucidum.

Locality. A single specimen of the female taken with the trawl from a depth of 1090 fathoms off Cape St. Vincent.

The segmentation of this genus presents only a very slight difference from that of *Phronima*, in which there are seven thoracic segments, while in *Thaumops* six only can be clearly discerned; but, as I have already observed, the second segment is larger than the others, and bears two pairs of limbs—the second pair of maxillipeds and the first pair of ambulatory legs. It is therefore probable that this segment represents two segments fused, in which case the segmentation of *Thaumops* would differ in no essential particular from that of *Phronima*.

The shape of the head and of the eyes in *Thaumops* is very peculiar, and so is the position of the antennæ. In the presence of a single pair only of antennæ, and in the antennæ being composed of two joints, *Thaumops* agrees with the female of *Phronima*; but in the former genus the antennæ are placed on the front of the head, while in the latter their place of attachment is close to the mouth.

The number of the joints of the legs is the same in both forms; for if we recognize the two pairs of maxillipeds as legs, we have in both Crustaceans seven pairs in the thoracic region. Even the claw which *Phronima* usually has on the fourth leg is represented here by the enlarged terminal joint of the last pair of thoracic legs.

The three pairs of abdominal feet and the segmentation of the abdomen present only very small differences from *Phronima*, in which there is one pair of appendages more than in *Thaumops*.

In both forms the nerve-chain shows five ganglia in the thoracic region. In the abdominal region *Thaumops* has three ganglia for five, *Phronima* five for five, segments.

Both forms alike have very large compound eyes, with an externally faceted cornea and crystalline bodies. The general conformation of the stomach in *Thaumops* is similar to that of *Phronima*, only in the former the cæcal appendage is developed to an extraordinary degree. The intestinal tube presents nothing remarkable. The heart is confined, as in *Phronima*, to the anterior part of the thoracic region, and the gills are three pairs, with nearly the same form and mode of attachment in both cases.

The genital papilla in *Thaumops* is in the centre of the first thoracic segment, while in *Phronima* it is in the seventh body-segment. The ovaries in *Thaumops* seem to be double, and are of a cylindrical form, while in most other known Amphipods they are cylindrical.

Thaumops is nearly related to *Phronima*; nevertheless I do not think it can form a member of the family Phronimidæ, as the transformation of the first two pairs of thoracic appendages into maxillipeds, the absence of mandibles, the entirely different structure of the head, the genital papilla being situated in the first body-segment, and the last pair only of the thoracic appendages being enlarged and bearing claws, seem to me to be characters of more than generic value.

As to the habit of life of *Thaumops*, the question arises whether it is a pelagic animal (like *Phronima*) which may have been caught in the trawl on its way up from the depth to which it had been lowered, 1090 fathoms, or whether it lives on the bottom. I have already given my reasons for thinking that this Crustacean is not a good swimmer, and for suggesting that it may, like *Nymphon*, live at the bottom; but I am well aware that these reasons are not sufficient to establish the point, which must be kept open to be decided by future observations.

DESCRIPTION OF THE PLATES.

PLATE XLIX.

Fig. 1. *Thaumops pellucida*, seen from below. $1\frac{1}{2}$ nat. size.
  A. Head with the cephalic ganglion and the nerves departing from it.
  o. The mouth.
  B. Five pairs of feet attached to the thoracic region.
  gp. Genital papilla.
  mx. Maxillipeds.

br. Branchiæ.
C. Three pairs of abdominal feet.
as. The anus.

Fig. 2. The same, seen from above. The head entirely covered by the faceted eyes (*oc*).
as. The anus.

Fig. 3. The same. View from the side.
oc. Eyes.
ap. Line of brownish appendages.
o. Mouth.
cæ. Gastric cæcum.
in. Intestine.
gp. Genital papilla.
ov. Ovary.
c. Heart.

PLATE L.

Fig. 4. Embryo in the egg, seen from above. ×70.

Fig. 5. The same, seen from the side. ×70.

Fig. 6. Papilla of the mouth (A) and genital papilla (B), seen from below. ×10.
ma. Maxillæ.
lab. Labium.
o. Opening of the mouth.
c. Depression for the oviducal apertures.
l. Breeding lamellæ.
sp. Small scarlet spines.
d. Large spine at the entrance of the vulva.

Fig. 7. Facets of the cornea. ×70. Represented diagrammatically.

Fig. 8. Chitinous appendages at the lateral line of the eye, showing also the chitinogenous layer of the carapace. ×120.

Fig. 9. Two pairs of crystalline bodies. ×120.

Fig. 9 *a.* Point of union of one pair of the crystalline bodies. ×120.

Fig. 1

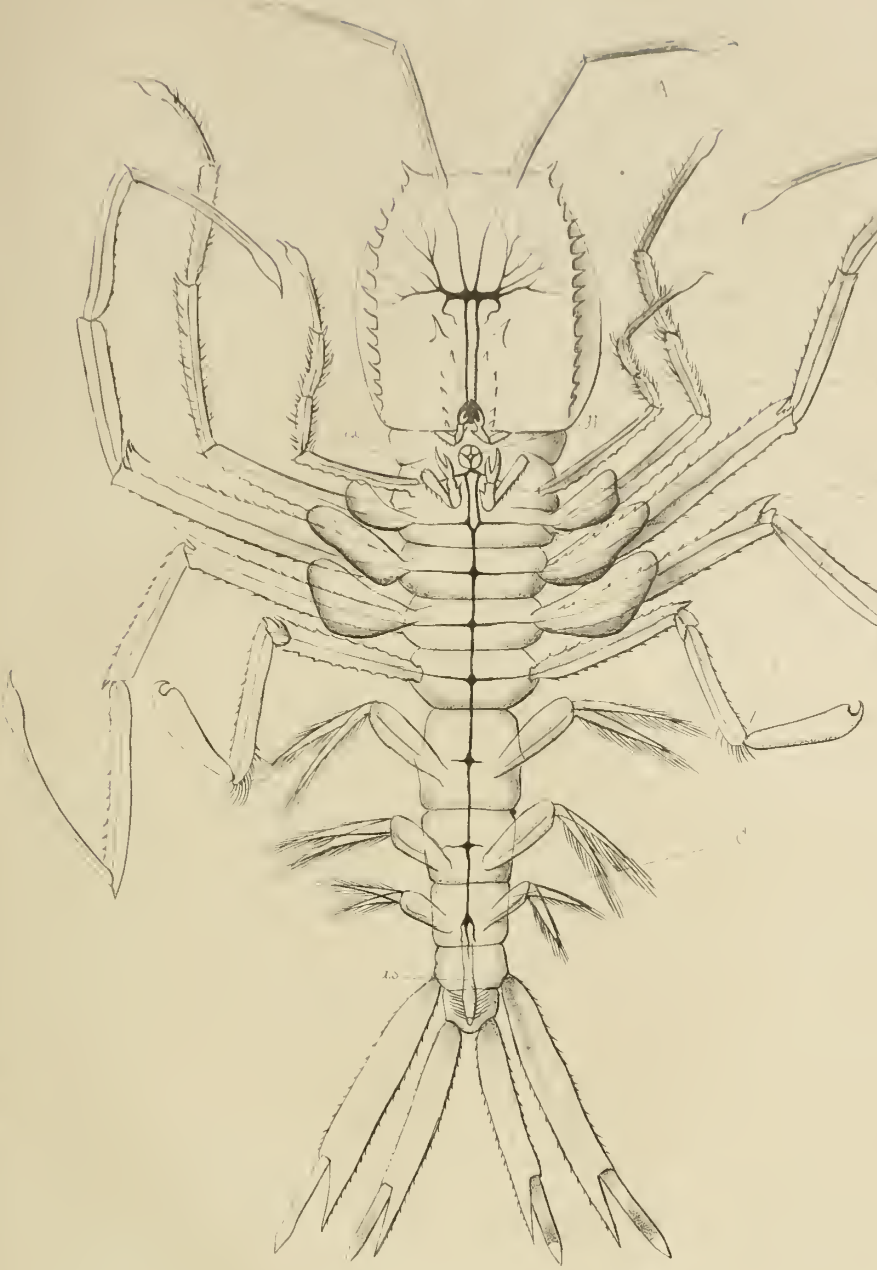


Fig. 2

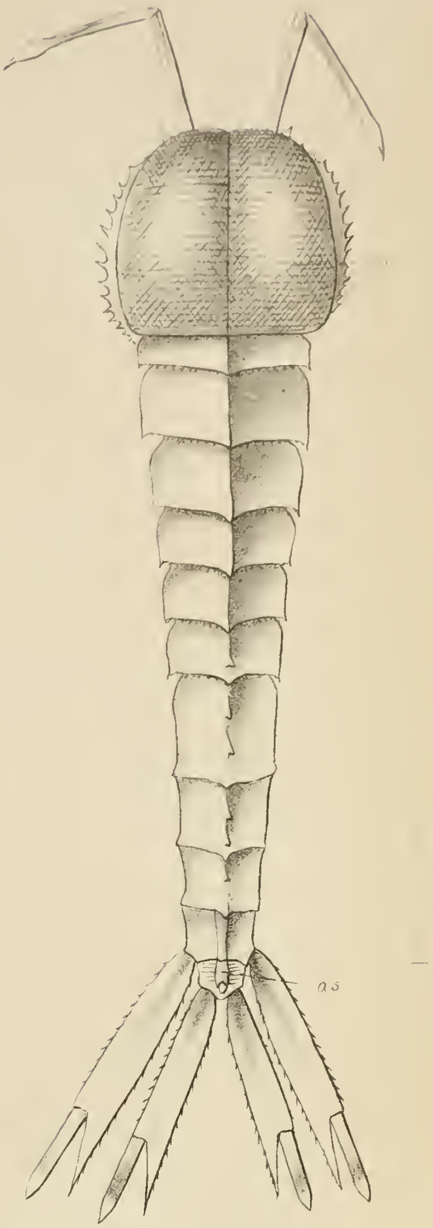
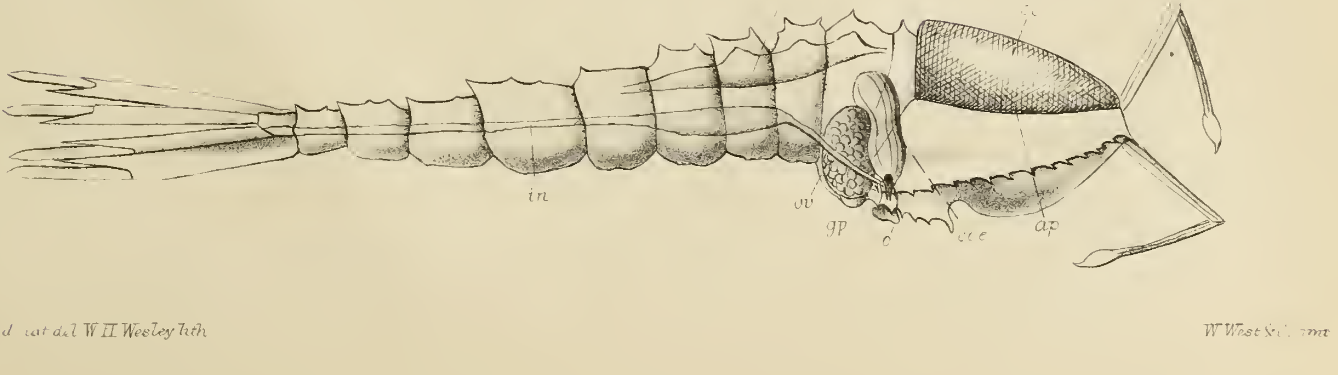


Fig. 3.



[illegible] Wood ad nat del W H Wesley lith

W West & Co imp

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

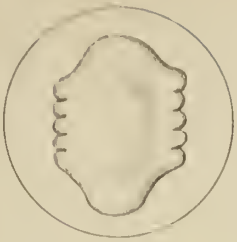


Fig. 4.

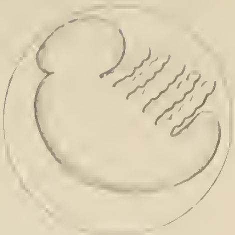


Fig. 5.

Fig. 6.

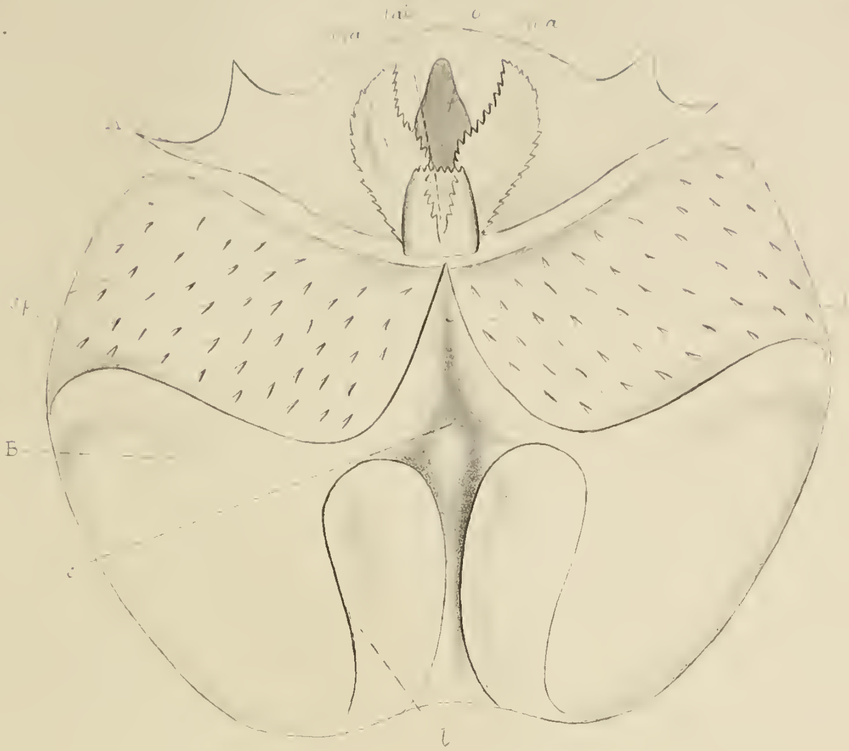


Fig. 7.

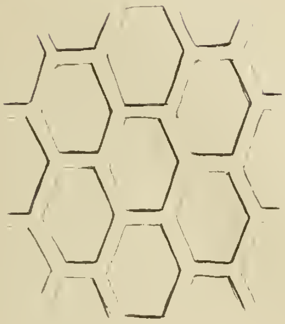


Fig. 8.

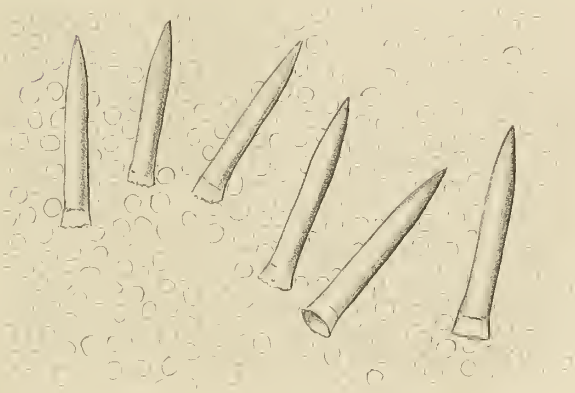
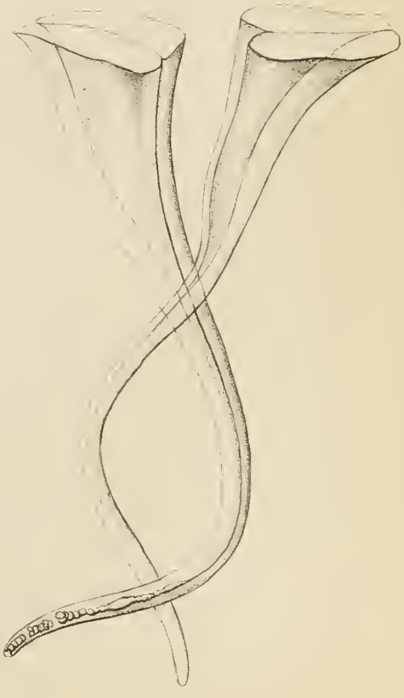


Fig. 9.



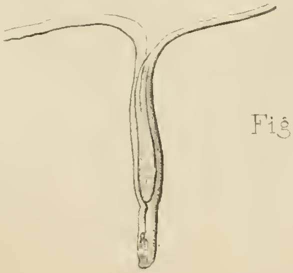


Fig. 9 a.

J.J Wild ad nat del. W.H Wesley lith.

W West & Co imp.

LIBRARY
OF THE
UNIVERSITY of ILLINOIS

APPENDIX.

On the Male and the Structure of Thaumops pellucida.

Received October 24,—Read December 11, 1873.

SINCE my paper on the large Hyperid was read at the Royal Society, three males of *Thaumops* have been caught by us. One of these, which was taken at the surface in the towing-net during the night, was very much spoiled; and I dissected its oral apparatus in order to elucidate several points about which I remained doubtful when I examined the female.

The largest of the males is 103 millims. in length, exceeding in length the large female by 19 millims., and showing that *Thaumops* attains a prodigious size. It was caught by the trawl in lat 5° 48′ N., long. 14° 20′ W. Another very well-preserved male is younger, only 46 millims. long, but shows the genital organs better. These males differ from the females by the absence of the genital openings at the base of the first segment and of the breeding lamellæ. The two elongate testes begin just behind the cæcum of the stomach, and their vasa deferentia run down to the last segment of the pereion, where they terminate by two simple openings between the last pair of pereiopods.

There is not a trace of a second pair of antennæ, either in the male or in the female. In the former, however, the first pair of antennæ, the five pairs of ambulatory pereiopods, and the caudal appendages are distinguished by the want of the glandular apparatus. In the female these glands cause an enlargement at the top of each of the appendages in question, and this enlargement is of course also wanting in the male.

The anterior antennæ have, in the large male, a length of 18 millims., and consist of two joints, the first of which is very short. The oral apparatus presents the same papillar shape which I figured in the female; but the mandibles, which at first I thought were entirely wanting, have now been found. They are very much like those of *Phronima*, only shorter and not so elongate as in that animal; the palpus, which is present in the mandibles of the male *Typhidæ*, could not be detected in *Thaumops*. The first maxillæ are also very small, and differ by their shortness from those of *Phronima*, but otherwise show the same characters. The second maxillæ could not be found with certainty; they are either wanting or represented by an organ which I thought was the labium (Plate L. fig. 6, *lab*). This organ arises from the second joint of a very peculiar appendage, which I have interpreted in my first paper as maxillæ (Plate L. fig. 6, *ma*). I am now satisfied, however, that these are the maxillipeds, consisting of three joints. Two of these joints are united together, the first being attached to the oral apparatus, and the second giving rise to a peculiar organ which consists of two chitinous claws united by a thin layer of the same substance, so as to form a sort of plate. I have already mentioned that I am not quite sure whether this is a labium or, as it seems more probable, the result of the displacement and union of the second maxillæ. This organ is situated at the inner side of the maxillipedes, the third joint of which consists of two strongly denticulated and separate claws. The two appendages (Plate XLIX. fig. 1, *mx*) which I first thought act as maxillæ are the gnathopoda of Spence Bate, followed by five pairs of pereiopods. The pleopods or swimmerets consist in the male, as well as in the female, of only three pairs.

All the other particulars described in the female may also be found in the male.

The question now arises whether the systematic position which I assigned to *Thaumops*, as a representative of a new family of *Hyperidæ*, to be placed next to the *Phronimæ*, can still be maintained. After having carefully examined the question, I think it not only can but must be maintained. As Professor Claus was kind enough to write to me, and as I had remarked already before getting his letter by studying living specimens of *Oxycephalus*, there are several points by which *Thaumops* approaches the *Typhidæ*, especially the elongate shape of the head, with the mouth underneath and the claws terminating the gnathopods. On the other hand, however, the want of the second antennæ in the male, the elongate slender shape of its first antennæ, which show nothing of the enlargement and the olfactory hairs peculiar to the male *Typhidæ*, and the want of the palpus in the male mandible, show that it differs widely from the *Typhidæ*. I therefore think that the position I first proposed for this animal is the right one. The characters, however, which I assigned to it must be changed somewhat in the following way.

THAUMOPS, nov. gen.

Caput oblongum, oculis maximis superiorem capitis partem tegentibus. Segmenta thoracica septem, abdominalia quinque. Antennarum in utroque sexu par unum. Mandibulæ et maxillæ minimæ. Maxillipedum par unum conjunctum. Pedum thoracicorum paria septem, anteriora duo parva et chelis armata. Pedum abdominalium paria tria.

Thaumops pellucida, n. sp.

Corpus longitudine 84–103 mm. In maris Atlantici parte septentrionali.

There is no doubt that *Thaumops* is a pelagic crustacean; and it is probably spread all over the Atlantic, for we got it off the coasts of Portugal and very near the equator. It was caught once at night in the towing-net and three times by the trawl, coming up from a great depth; therefore it seems probable that, like many other pelagic animals which in the daytime live in a depth of 40–100 fathoms and come up only in the night, it retreats to a considerable depth; and this is probably the reason why it has so long remained unknown.

H.M.S. 'Challenger,' Bahia, September 1873.

XVIII. *Researches in Spectrum-Analysis in connexion with the Spectrum of the Sun.—No. II.*

By J. Norman Lockyer, *F.R.S.*

Received March 14,—Read May 8, 1873.

Contents.

- Introduction.
- I. Chemical compounds.
  - α. Conditions of the experiments.
  - β. Results of experiments.
    - Lead.
    - Barium.
    - Strontium and Magnesium.
    - Sodium.
    - Lithium.
  - γ. On the difference between flame-spectra and those produced by a weak electric discharge.
    - Barium.
    - Strontium.
    - Conclusions.
  - δ. Experiments to determine the cause of the similarity of the spectra of the various salts observed in air.
    - Conditions of the experiments.
    - Spectra of Strontium salts.
    - Conclusion.
  - ε. Considerations which follow from the above observations in connexion with the spectra of chemical compounds.
    - General discussion of spectra.
    - Bearing of the new observations.
    - General statement.
    - Spectra of the metalloids.
  - ζ. Applications of these considerations to solar and stellar spectra.
- II. Mechanical mixtures.
  - Method employed in preparing mixtures.
  - Observations.
  - Application of these observations to the solar spectrum.

In my former communication under the above title I pointed out that the new method of spectroscopic research adopted by Dr. Frankland and myself had enabled me to establish:—

(1) That when a metallic vapour is subjected to admixture with another gas or vapour, or to reduced pressure, its spectrum becomes simplified by the abstraction of the shortest lines and by the thinning of many lines.

(2) That when metals are chemically combined with another element (I used chlorine) only the longest lines of the metal remain in the spectrum of the chloride—the number being large in the case of elements of low atomic weight, and small in the case of elements of high atomic weight and of twice the atom-fixing power of hydrogen.

(3) That I had reason to believe that by means of mechanical admixtures the spectrum of a metal could be made simple in the same manner, thereby giving a foreshadowing of a quantitative spectrum-analysis.

I then showed the bearing of these determinations on several questions connected with Solar Physics.

I have now the honour of communicating to the Royal Society the results of the continuation of my inquiries.

I. CHEMICAL COMPOUNDS.

In extension of the former experiments to which I have alluded, it became of importance to try several series of salts in which the atomic weights varied :

1st. In each series.

2nd. In the associated elements in each series.

With this view the spectra of the following series were mapped :—

PbF_2, $PbCl_2$, $PbBr_2$, PbI_2;
SrF_2, $SrCl_2$, $SrBr_2$, SrI_2;
BaF_2, $BaCl_2$, $BaBr_2$, BaI_2;
MgF_2, $MgCl_2$, $MgBr_2$, MgI_2;
NaF, $NaCl$, $NaBr$, NaI.

Conditions of the Experiments.

The conditions of the experiments were as follows :—The salts were rammed into the small aluminium cups described in the former paper, and the cups fastened to copper rods which passed through a cork into the interior of a wide glass tube. An aluminium point* formed, as in the former experiments, the opposite pole, which was also fastened to a copper rod passing through a cork fitted into the opposite end of the tube. Both corks were pierced and furnished with narrow glass tubes; one of these served to admit hydrogen, while the opposite one served as an exit-tube for the gas. The hydrogen was prepared from zinc and sulphuric acid, and passed first through a scrubber filled with broken pumice-stone saturated with solution of plumbic acetate to free it from sulphuretted hydrogen, then through a wash-bottle containing concentrated sulphuric acid, and lastly through a tube containing fragments of sodium, the latter serving both as a drying tube and freeing the gas from any acid mechanically carried over by it.

The hydrogen thus purified was admitted in a gentle stream into the tube containing the poles, and the spark was then passed, the induction-coil already mentioned being used. When it was desired simply to observe the spark in air, the hydrogen apparatus was disconnected, or the poles were placed in an ordinary spark-stand.

---

* "An examination of the spectrum of the spark by the new method shows that the light given out by the discharge depends upon the amount of vapour lying between the poles, and that if both poles are composed of equally volatile metals, or the same metal, the bridge is formed by an equal, or nearly equal, amount of vapour lying round each pole; hence, supposing that the vapours do not intermingle, it follows that the longest line can only be half the length of the actual distance between the poles.

"When, however, the poles are unequally volatile, the bridge appears to be formed entirely of vapour from the most volatile pole; hence the longest line can extend almost or quite across the space from pole to pole.

"It was on account of these observations that aluminium was used for the poles in the experiments described, it having been found that that metal was extremely refractory in the spark, *i.e.* that all its lines in the most visible portions of the spectrum were very short—the vapour which extended above the short line region being practically capable of giving but the two lines of aluminium which fall between H_1 and H_2.

"There are, however, many phenomena in connexion with this which are well worth study; for instance, in a case where the spectrum of copper was examined with a plumbago point opposite to the copper pole, the effect of the former was shown by the remarkable way in which the copper lines were shortened. Even when the poles were almost touching, the copper lines were confined to the copper pole, and did not extend across the spectrum."—*Extracts from Laboratory Notebook, 23rd September and 30th October*, 1872.

Results of Experiments.

The following are the results of some experiments made with the spark in air, the jar being thrown out of the circuit.

LEAD.

Plumbic Fluoride, PbF_2.—It will be seen on referring to the map of this spectrum (Plate LI.) that the eleven longest lines of the following wave-lengths*, 4167·5, 4246·0, 4386·5, 5163·0, 5372·0, 5523·5, 5546·0, 5607·0, 6040·0, 6059·0, and 6452·0, were seen.

Of these it is to be remarked that 4246·0 and 4386·5 are only seen for a short time when the spark first begins to pass, 6452·0 is very faint, and 5523·5 very short; so that practically the spectrum contains but seven distinctly visible lines.

Plumbic Chloride, $PbCl_2$.—On observing the spectrum of this salt, it is found to have been simplified in the following manner:—

The lines left are 4167·5, 5163·0, 5372·0, 5523·5, 5546·0, 5607·0, 6040·0, 6059·0, and 6452·0, nine in number; 5523·5 has become excessively short, and 6452·0 rather brighter than it was in the fluoride.

Plumbic Bromide, $PbBr_2$.—4167·5 still maintains its brilliancy undimmed, 5163·0, 5372·0, 5546·0, and 5607·0 remain; 5523·5 is just distinguishable as a dot on the pole, but 6040·0, 6059·0, and 6452·0 are completely lost, the spectrum thus being reduced to five lines.

Plumbic Iodide, PbI_2.—4167·5 is little or not at all altered in appearance, 5163·0, 5372·0, 5607·0 yet remain; 5546·0 has become a dot, and faint indications of 5523·5, in the same state but much fainter, are visible.

The composition by weight of these compounds is as follows:—

PbF_2,	Pb to F	1·0 to 0·18
$PbCl_2$,	Pb „ Cl	1·0 „ 0·34
$PbBr_2$,	Pb „ Br	1·0 „ 0·77
PbI_2,	Pb „ I	1·0 „ 1·22

If these results are expressed in another way, by making the non-metallic element unity, we have:—

PbF_2,	F to Pb	1·0 to 5·4
$PbCl_2$,	Cl „ Pb	1·0 „ 2·9
$PbBr_2$,	Br „ Pb	1·0 „ 1·2
PbI_2,	I „ Pb	1·0 „ 0·8

Now the lines in the spectrum of lead increase in length and number as we ascend the above series, *i. e.* as the percentage weight of lead increases, as is shown in the second

---

* From THALÉN's observations.

Table. The fact may then be simply stated, that in the case of lead the complexity of the spectrum increases as the atomic weight of the non-metallic element with which it is combined decreases.

BARIUM.

The next metal experimented on was barium, an element of much lower atomic weight than lead, and in this respect occupying a position not very much above the mean atomic weight of the elements. It was soon found that the facts observed with lead did not completely hold with regard to barium, although they include the phenomena presented by the chloride, bromide, and iodide. Even with these salts, however, the phenomena, though the same in kind, differ somewhat in degree. For instance, the same number of metallic lines was observed in all these salts, and between the appearance of the chloride and the bromide spectrum there was no appreciable difference. In the case of the iodide, however, there was a sensible change in the direction expected from the behaviour of lead—*i. e.* the spectrum became dimmer, that is, exhibited a tendency to die out.

When, however, baric fluoride was examined, a different state of things was observed. Instead of the spectrum becoming more complex it became simpler, exhibiting in fact only the four longest lines of barium with any degree of distinctness, and these showing but little brilliancy.

STRONTIUM and MAGNESIUM.

Strontium behaved in this particular in the same way as barium did, the falling off of the lines in the fluoride being very marked. In the case of magnesium (which, as regards its chloride, bromide, and iodide, followed the behaviour of the alkali metals, to which I shall immediately refer, rather than that of barium and strontium), the fluoride exhibited the same stubborn resistance to the action of the spark. It is to be remarked that these three fluorides are non-volatile, and so infusible that even after long exposure to the current there was little or no indication of coherence; in fact, in the case of magnesic fluoride, the salt was distinctly seen to be blown out of the cup as a cloud of dust, and when one of these particles was converted into vapour in the spark, the spectrum exhibited fragments of lines *sharp at both ends.*

On blowing a cloud of magnesic fluoride in fine powder through the spark, *b* in particular was seen as a series of three pointed lines.

It will be seen from the above experiments, and from the annexed map of the strontium salts observed in air (Plate LI.) taken as a type of this group, that the general statement made for lead does not apply to barium or strontium, the chlorides, bromides, and iodides of which metals are pretty equally volatile, while their fluorides are apparently not readily volatile at any temperature which I could employ.

SODIUM.

Sodium and lithium, elements of low atomic weight, were the next metals experimented upon.

Some *sodic fluoride* was inserted into one of the aluminium cups, and opposite was placed a clean blunt aluminium point*; the small coil and a jar were employed.

On passing the spark, D only was seen. The break was then readjusted and the spark made heavier, but the result was the same. Some new and moist sodic fluoride was then placed in the cup, but the result still remained as before.

Sodic Chloride was then treated in the same way, a fresh aluminium pole being reserved for it and placed opposite to its cup. D was present and was bright; the double line in the red once flashed in, but it was not again seen though the cup was charged and recharged with the salt repeatedly.

Sodic Bromide treated in the same way gave D, the red line being seen but once; D, however, was brighter than before.

Sodic Iodide treated as above gave D and the red double line, which remain constantly visible, the double green line near D being also occasionally seen. D was intensely brilliant, and the salt fumed away from the pole in a dense white smoke.

The following day a fresh attack with more powerful apparatus was made. One of App's 6-inch quantity coils and a jar with about 224 square inches of coated surface were employed with a powerful battery of five one-pint Grove's cells. The results, however, went exactly in the same way. Na I and Na Br gave all the metallic lines of sodium, which were very brilliant; whilst Na Cl gave D and the double red very bright, and stretching all across the spectrum. Na F gave also D and the double red line; but the latter only extended three quarters across the spectrum, and neither D nor the red line was so bright as they were in the chloride. Further observations showed that under certain circumstances all the lines appeared even in these latter salts; but they were so dim as to be scarcely visible, and the fact of these compounds behaving in direct contravention to the observations with lead was established.

LITHIUM.

The following experiments were made with lithic iodide and chloride in coal-gas.

Lithic Iodide gave the red line of this metal, 6705, extending all across the spectrum, but it was very faint. 6102, the orange line, was very brilliant and about two thirds across. 4603, the blue line, was very short and nebulous when seen, which was only on one occasion. This differs but little from the spectrum given by the metal itself, except that the lines are in the latter case much brighter, and that the red and orange extend right across the spectrum, and the blue three quarters across.

A line at 4972 was seen also in the spectrum when the metal was used; but this has never been seen by Kirchhoff, Thalén, or any other observer except Huggins, in lithium.

Thalén, however, saw this line alone in cæsium, of which metal it constitutes the entire spectrum.

Huggins has nevertheless included this line in his map of the lithium spectrum. But there can be no doubt that it is the cæsium line, and that it is due to the presence of a trace of cæsium existing as an impurity in the lithium, as it does not appear in the spectrum of the pure salts; and no one but Dr. HUGGINS has seen it in lithium, at any rate with sufficient distinctness to consider himself justified in including it in a map or list.

---

* Special precautions being taken to keep the poles the same distance apart in all the experiments.

Lithic Chloride gave 6705·2, the red line, thin and faint, but all across the spectrum; the orange very bright and across the spectrum; the blue line was also visible, but it did not extend across the spectrum.

It will be seen from the above that lithium, the least electro-positive of the alkali metals, approaches in its spectroscopic behaviour the metals of the alkaline earths, strontium and barium, as it approaches them in some points of its chemical behaviour. Thus the spectrum of its iodide differs from that of the chloride as the spectrum of baric iodide differs from that of baric chloride, and not as the spectrum of sodic iodide does from sodic chloride, as might have first been supposed from the usual position, among the alkalies, assigned to the metal.

On the difference between Flame-spectra and those produced by a weak electric discharge.

The following experiments were made with beads of the various substances mentioned, heated in the Bunsen flame on loops of platinum wire.

BARIUM.

Baric Iodide.—This salt gave the spectrum since proved to be due to the oxide and the line 5534·5 very distinctly; it coloured the flame a greenish yellow, and fused to a globule.

Baric Bromide gave the oxide spectrum and 5534·5 with difficulty; the spectrum was not very bright, and the flame but little coloured.

Baric Chloride gave the same spectrum as the two salts mentioned above; but the spectrum was much brighter, and the flame was coloured a bright pale green.

Baric Fluoride gave scarcely a trace of the oxide spectrum, and 5534·5 was very faint indeed; but no signs of fusion were visible, no bead being formed, and the flame was only coloured slightly and in parts.

STRONTIUM.

Strontic Iodide, heated on platinum wire in the Bunsen flame, gives the spectrum in the red, so well represented in BUNSEN'S and KIRCHHOFF'S drawing, and the great blue line 4607·5 of the metal.

Strontic Bromide behaves much as the iodide does, but shows more of the structure in the red. 4607·5 is also always present, and is very bright, a considerable change from its appearance in the iodide, in the spectrum of which it is for a time faint and then becomes brighter.

Strontic Chloride gives the bands very brightly at first, but not so brightly after a time; 4607·5 is fainter, but is very distinct.

Strontic Fluoride refused to give any trace either of the strontium or compound spectrum; it is, in fact, only capable of being heated to a white heat and giving a continuous spectrum.

Conclusions.

It is to be observed, then, that when the spectra before referred to produced by flames are compared with those produced by the low-tension spark, the spectra of the metals in the combination are in the former case invariably more simple than in the latter, and that they are *simplified to such an extent that only the very longest line is left*; thus:—

Baric Iodide with the low-tension spark gives five and twenty lines. In the flame it gives but one, and that the longest, namely 5534·5.

Baric Bromide gives five and twenty lines with the spark; only one in the flame, the same longest line 5534·5.

Baric Chloride five and twenty lines in spark and one, 5534·5, in flame.

Baric Fluoride four lines in spark, 5534·5 alone in flame.

Again, taking the case of strontium, we find that in the case of strontic iodide thirty-two lines are observed in the spark, one alone in the flame, and that is the longest, namely 4607·5, a line by far the longest in the spectrum of strontium.

Strontic Bromide gives also thirty-two lines in the spark and but one in the flame, the same longest line 4607·5.

Strontic Chloride gives thirty-two lines in the spark, but only this one, 4607·5, in the flame.

Strontic Fluoride gives fourteen lines in the spark, but in the flame does not even give the longest line. There is, in fact, no spectrum at all due either to the metal or the compound.

It is especially to be remarked that strontic oxide furnishes us with an intermediate condition of things between the chloride and fluoride.

In this compound the band near D is the only representative of the spectrum of the compound. The longest metallic line, 4607·5, is also invisible. We are justified, therefore, in assuming that only a small quantity of the undissociated compound is present in the reaction.

Experiments to determine the cause of the similarity of the spectra of the various salts observed in air.

It was noticed in the earliest observations of the spectra of salts in the spark that after a time the spectrum was nearly the same, whatever salt had been placed in the cup. I therefore determined upon a careful study of the phenomena when the salt was submitted to the heat of the ordinary Bunsen flame; and after some preliminary observations, I requested Mr. Friswell to make a detailed examination of the various stages of the reactions in question. I now append his observations, which, taken in connexion with the other branches of the inquiry, clearly establish that the band spectrum is that of the oxide.

Conditions of the Experiments.

The observations about to be detailed were made as follows:—

The large Steinheil spectroscope was used with four prisms, such as were used for the ordinary observations of the metallic spectra with the spark.

The slit was, however, wider. The salt was placed in a tangled loop on a piece of platinum wire held in a clip. The source of heat was a small Bunsen burner.

Spectra of Strontium Salts.

Strontic Iodide.—When the wire was first inserted into the flame the salt fused, and the flame showed an intense yellow coloration.

The spectrum during this stage exhibited the D line very strongly, and the orange band of the strontic salt spectrum lying just on the least refrangible side of D; *but the metallic line* 4607·5 *was invisible*, or at the best but very faint.

If the fused bead be now quickly withdrawn from the flame and held in front of a sheet of white paper, it is seen to be evolving dense violet fumes of iodine. If the bead be again thrust into the flame and the heat continued, it gradually becomes less and less fusible, and ultimately solidifies; the yellow tinge now vanishes from the flame, and D drops out of the spectrum, the flame becoming red; the band spectrum and 4607·5 are now very brilliant, and the solidified mass becomes white-hot and emits a continuous spectrum. If it be placed in a test-tube and treated with an acid it effervesces; and if submitted to the action of nitric acid and starch no blue colour is produced.

Evidently, then, the iodine has been driven off, and the mass consists in all probability mainly of strontic oxide with some strontic carbonate.

It seems then that the breaking up of the compound and the volatilization of the iodine consume so much heat that the $Sr\,I_2$ never gets sufficiently heated to enable it to be volatilized; and hence we should not see its spectrum even were the flame sufficiently hot to render its vapour luminous, and the body sufficiently stable to bear such a heat without decomposition. The fact, however, is, that what spectrum is seen is produced by the decomposing action of the flame acting either on small quantities of the $Sr\,I_2$, which do get volatilized, or, what is more probable, are mechanically carried off by the ascending currents of iodine vapour. It is to be remarked that when the bead has become infusible the spectrum begins to die out; the orange band then only appears very faintly, and 4607·5 has utterly gone. We then have the non-volatile oxide only left in the flame, and it of course cannot give any thing but the continuous spectrum due to its own incandescence.

Strontic Bromide behaves very much in the same manner as the iodide, the difference that exists depending on the greater stability of the latter compound in the flame. On removing the bead but slight fuming is observable, and there is very little odour of bromine. After the bead has been roasted for a long time it still evolves bromine, when treated with sulphuric acid and manganic oxide.

Strontic Chloride never shows any tendency to undergo decomposition; it remains clearly transparent and fusible to the end, and evolves chlorine when treated for that purpose.

Strontic Fluoride was the most stable of all; it would not fuse, gave no coloration to the flame, and obstinately retained its fluorine to the last, as was shown by the mass giving the usual reaction of fluorine when treated on a glass plate with sulphuric acid.

CONCLUSION.

These facts justify us in coming to the conclusion that the similarity of the spectra observed under the conditions in question is due to the fact that the spectrum observed is that of the oxide; for whereas in the first instance there is a differentiation between the various spectra, after the action of the flame has been continued for some little time the spectra observed are the same.

Considerations which follow from the above observations in connexion with the spectra of chemical compounds.

GENERAL DISCUSSION OF SPECTRA.

In what has been said before, both in this communication and in my former paper on the spectra of chemical compounds, I have only referred to the lines of the metals.

I now propose to discuss the spectra generally.

Some of the earliest observations of this nature (1860) have been described by KIRCHHOFF and BUNSEN*. They remark, "We have compared the spectra represented on the Plate†, which we have obtained from the pure chlorides, with those produced when the bromides, iodides, hydrated oxides, sulphates, and carbonates of the several metals are brought into the following flames:—

"Into the flame of sulphur.
,, ,, bisulphide of carbon.
,, ,, aqueous alcohol.
Into the non-luminous flame of coal-gas.
Into the flame of carbonic oxide.
,, ,, hydrogen.
Into the oxyhydrogen flame.

"As the result of these somewhat lengthy experiments, the details of which we here omit, it appears that the alteration of the bodies with which the metals employed were combined, the variety in the nature of the chemical processes occurring in the several flames, and the wide differences of temperature which these flames exhibit, *produce no effect upon the position of the bright lines in the spectrum which are characteristic of each metal.*

"It was found that the same metallic compound, placed in one of these flames, gives a more intense spectrum the higher the temperature of the flame. In the same flame, those of the compounds of a metal give the brightest spectra which are most volatile.

---

* Translated in Philosophical Magazine, 1860, vol. xx. pp. 91–93.

† The spectra shown on the Plate are those known as flame-spectra.

"In order to prove still more conclusively that each of the above-mentioned metals always produces the same bright lines in the spectrum, we have compared the spectra represented in the Plate with those produced when the electric spark passes between electrodes made of these metals.

"Small pieces of sodium, potassium, lithium, strontium, and calcium were fastened to fine platinum wires and melted two by two into glass tubes, so that the pieces of metal were separated by about 1 to 2 millims., and the platinum wires were melted through the sides of the glass tubes. Each of these tubes was placed in front of the spectrum-instrument, and by means of a Ruhmkorff's induction-apparatus*, sparks were allowed to pass between the pieces of metal inside the tube; the spectrum thus produced was then compared with that given by a gas-flame in which the chloride of the metal was brought. The flame was placed behind the glass tube. By alternately bringing the induction-apparatus into and out of action, it was easy, without measuring, to convince ourselves that in the brilliant spectrum of the electric spark, the bright lines of the flame-spectrum were present in their right position. Besides these lines, other bright ones appeared in the electric-spark spectrum; some of these were produced by foreign metals present in the electrodes, others arose from nitrogen, which filled the tubes after the oxygen had combined with a portion of the electrodes"†.

As already mentioned in a note, the Plate given with this communication shows that the spectra thus referred to by the illustrious German chemists were the flame-spectra of the elements in question.

This question was advanced in 1862 by MITSCHERLICH‡ and by Professors ROSCOE and CLIFTON§, from whose memoirs I proceed to give extracts, and in 1865 by DIACON‖. MITSCHERLICH, in his memoir, after detailing some experiments, goes on to remark:—

"It follows from these experiments that metallic compounds do not always give a spectrum, and that in the case of those that do, the spectra are not always the same; and, further, that the spectra are different when they are due to a metal or its combinations. We have also the right to conclude that each binary compound which gives a spectrum gives one peculiar to itself, excepting always of course when the combination is destroyed by the flame. Up to the present time we are acquainted with little beyond the spectra of the metals themselves, by reason of the facility with which the flame reduces their combinations.

"Up to the present time also it has been admitted that metals always give the same spectra with whatever they are combined¶. As in the above experiments this was not found to be the case, it became necessary to determine whether the ordinary spectra are due to the metals or their oxides, since according to my experiments all compounds which contain the metal in the form of oxide give the same spectra."

---

* No mention is made of a jar, which doubtless was not employed.

† I shall produce evidence in the sequel to show that this explanation is probably not the correct one.

‡ Ann. de Chim. et de Phys. 1862, p. 175.

§ Trans. Lit. and Phil. Society, Manchester, 1862.

‖ Annales de Chimie et de Physique, 4 ser. vol. vi. p. 5.

¶ This is a reference to KIRCHHOFF's and BUNSEN's paper just quoted.

As a result of his experiments on sodium, he states that in the flames which give the line of sodium the spectrum is due to the metals and not to the oxide. Hence he concludes that in the case of oxides the spectrum is the spectrum of the metals*.

He then states that the new lines which had then lately been discovered without corresponding elemental lines were probably due to binary compounds.

The main view in MITSCHERLICH's paper, that each binary compound has a spectrum of its own, is borne out by the conclusion arrived at by CLIFTON and ROSCOE, who remark in their paper above referred to :—

"KIRCHHOFF, in his interesting memoir on the Solar Spectrum and the Spectra of the Chemical Elements, noticed in the case of the calcium-spectrum that bright lines which were invisible at the temperature of the coal-gas flame became visible when the temperature of the incandescent vapour reached that of the intense electric spark. We have confirmed this observation of KIRCHHOFF's, and have extended it, inasmuch as we, in the first place, have noticed that a similar change occurs in the spectra of strontium and barium ; and, in the second place, that not only new lines appear at the high temperature of the intense spark, but that the broad bands characteristic of the metal or metallic compound at the low temperature of the flame or weak spark totally disappear at the higher temperature. The new bright lines which supply the part of the broad bands are generally not coincident with any part of the band, sometimes being less and sometimes more refrangible. Thus the broad band in the flame-spectrum of calcium named Ca β is replaced in the spectrum of the intense calcium-spark by five fine green lines, all of which are less refrangible than any part of the band Ca β ; whilst in the place of the red or orange Ca α, three more refrangible red or orange lines are seen. The total disappearance in the spark of a well-defined yellow band seen in the calcium-spectrum at the lower temperature was strikingly evident. We have assured ourselves, by repeated observations, that in like manner the broad bands produced in the flame-spectra of strontium and barium compounds, and especially Sr α, Sr β, Sr γ, Ba α, Ba β, Ba γ, Ba δ, Ba ε, Ba η, disappear entirely in the spectra of the intense spark, and that new bright non-coincident lines appear. The blue Sr δ line does not alter either in intensity or in position with alterations of temperature thus effected; but, as has already been stated, four new violet lines appear in the spectrum of strontium at the higher temperature.

"If, in the present incomplete condition of this most interesting branch of inquiry, we may be allowed to express an opinion as to the possible cause of the phenomenon of the disappearance of the broad bands and the production of the bright lines, we would suggest that, at the lower temperature of the flame or weak spark, the spectrum observed is produced by the glowing vapour of some compound, probably the oxide, of the difficultly reducible metals; whereas at the enormously high temperature of the intense electric spark these compounds are split up, and thus the true spectrum of the metals is obtained."

---

* This opinion he corrects in his next communication, to which reference will be made hereafter.

Two years later (in 1864) MITSCHERLICH, in a second communication*, expanded his views and brings an overwhelming mass of evidence in favour of them. The methods he employed were as follows:—

The substances were heated:

1. In the flame of a Bunsen burner.
2. In the flame of coal-gas burning in oxygen.
3. In the flame of hydrogen burning in chlorine.
4. In the flame of mixtures of hydrogen and bromine or iodine-vapour burning in air or oxygen.
5. *In the case of combustible gases* they were allowed to emerge out of the middle aperture of an oxyhydrogen burner, and were burnt in air or oxygen.

In *the case of non-combustible gases* they were mixed with a combustible gas, such as carbonic oxide or hydrogen.

6. *In the case of solid substances* they were introduced into a tube one end of which was connected with a Rose's hydrogen-apparatus; the substance was then volatilized, and the gas kindled at the other end of the tube.
7. Or the spark was taken between *poles* containing the metal or compound *in any gas*; or between,
8. *Liquid electrodes*, in which the temperature is much lower than in 7.

From the beautiful series of researches carried on by these several methods, he concludes "that every compound of the first order which is not decomposed, and is heated to a temperature adequate for the production of light, exhibits a spectrum peculiar to this compound, and independent of other circumstances."

BEARING OF THE NEW OBSERVATIONS.

The experiments I have lately made, taken in conjunction with my determination of the long and short lines of metallic vapours, and the consequent simplification of the spectra by the reduction of pressure or molecular distance, set this question at rest, and in the direction indicated by MITSCHERLICH, CLIFTON, ROSCOE, and DIACON; while much light has been thrown upon all the prior observations, as a consequence of which they are brought much more into harmony than at first appeared.

First. I have observed† that whether the spectra of iodides, bromides, &c. be observed in the flame or weak spark, *in air*, the spectrum is in the main the same, as maintained by KIRCHHOFF and BUNSEN; but that this is not the spectrum of the metal is established by the facts, *that with a low temperature only the longest lines of the metals are present*, showing that only a small quantity of the simple metal is present as a result of partial dissociation, and that by increasing the temperature, and consequently the amount of dissociation, *the other lines of the metals appear in the order of their length with each rise of temperature.*

---

[*] Translated in Philosophical Magazine, 1864, vol. xxviii. p. 169.

[†] See *antè*, p. 645.

Secondly. I have convinced myself that this is the spectrum of the oxide, because *in air*, after the first application of heat, the spectra *and metallic lines are in the main the same*, while *in hydrogen* the spectra are different for each compound, *and true metallic lines are represented according to the volatility of the compound, only the very longest lines being visible in the spectrum of the least volatile compound.*

In proof of this statement I append a drawing (Plate LII.), on the scale of the maps of the last paper, representing the spectra of the chloride, bromide, and iodide of strontium. In order to avoid the introduction of the oxide spectrum, and so to secure the differentiation of the three spectra if possible, they were observed in hydrogen, which gas had been carefully treated in such a manner as to secure as far as possible the exclusion of any trace of oxygen. It will be seen at a glance that the spectra differ not only from the spectrum given by the metal, or by its salts in air at a high temperature, but considerably amongst themselves. In the experiments care was taken to keep the spark temperature as low as possible; and of course no jar was used, its presence in the circuit being instantly felt by the introduction of large numbers of metallic lines and the disappearance of the banded spectrum.

The drawings were made from readings of the scale of the Steinheil spectroscope, and then approximately laid down on a scale of wave-lengths.

General Statement.

These and other facts which I have observed can be included in a general statement such as the following.

1. A compound body, such as we have been considering, has as definite a spectrum as a simple one; but while the spectrum of a simple metal consists of lines, the number and thickness of some of which increase with molecular approach, the spectrum of the compound consists in the main of channelled spaces and bands, which increase in like manner. In short, the molecules of a simple body and a compound one are affected in the same manner by their approach or recess, in so far as their spectra are concerned; *in other words, both spectra have their long and short lines*, the lines in the spectrum of the element being represented by bands or channelled lines in the spectrum of the compound; and in each case the greatest simplicity of the spectrum depends upon the greatest separation of molecules, and the greatest complexity (a continuous spectrum) upon their nearest approach.

2. The heat required to act upon a compound, so as to render its spectrum visible, dissociates the compound according to its volatility: the number of true metallic lines which thus appear is a measure of the dissociation; and as the metal lines *increase in number*, the compound bands *thin* out*.

---

* The above statement is confirmed by the following experiments. A bead of strontic chloride was interposed between two aluminium electrodes; the induced current, without a jar, was then passed. The red-band spectrum of the oxide was very intense, and the only metallic *line* of any strength was 4607·5. The wire and bead soon became red-hot, and the latter evaporated, the spectrum disappearing. A jar of 186 square centims.

It will be seen from the above that my researches have convinced me that the opinion held by the illustrious ÅNGSTRÖM, that metallic elements (in which I include hydrogen) have only one spectrum, is the only tenable one; and it is to be hoped that science will soon be enriched by the results of more experiments similar to those recently made with such success by Mr. SCHUSTER.

SPECTRA OF THE METALLOIDS.

MITSCHERLICH, in the paper to which I have so often referred, calls attention to the fact that the metalloids show the same spectra with regular shading as compound bodies; but I think there is the difference to be remarked that, as a rule, the structure of the spectrum of the metalloids extends further along the spectrum from the least refrangible end than in the case of the spectra of compound bodies. As I do not think it is too much to say that, as a rule, the lines of the metallic elements are more prominent in the green and more refrangible parts of the spectrum than in the red (which may even be gathered from an inspection of the solar spectrum), the question arises whether it be a possibility that the molecules of a metalloid, in structure, lie between those of elements on the one hand and compounds on the other.

Applications of these considerations to Solar and Stellar Spectra.

MITSCHERLICH, in his first memoir, thus refers to the bearing of his observations with regard to the solar spectrum :—

"Ces essais montrent comment l'analyse spectrale peut conduire à la connaissance des affinités mutuelles des corps simples à la température de l'atmosphère solaire. Si l'on observait, par exemple, le spectre d'un chlorure alcalin terreux dans la lumière du soleil, on en pourrait conclure que son métal possède, à la température du soleil, une affinité pour le chlore plus grande que le potassium ou le sodium, ces derniers métaux existant à l'état de liberté. Reciproquement, la connaissance des combinaisons existant dans l'atmosphère solaire pourra conduire à connaître la température de cet astre, si toutefois nous ne parvenons jamais nous-mêmes à approcher de cette température.

"La présence du sodium libre dans l'atmosphère conduit à admettre qu'il n'y existe pas de corps electro-négatifs libres, tels que l'oxygène ou le soufre, et qu'ils n'y existent même pas autrement en quantité assez abondante pour se combiner avec tout le sodium.

---

coated surface was then introduced into the secondary current. The metallic lines appeared all along the spectrum, the "structure" (oxide spectrum) became fainter, and its intervals wider; the bead soon became red-hot. A jar of 467 centims. gave lines only and no structure, and one of 2214 centims. the same result, the bead remaining cold.

On using the bead as the electrode, the results were nearly the same; but the heating-effect continued when somewhat larger jars were used than the one with 362 centims., which did not show this effect with the former arrangement. When the slit was very narrow it was observed that several of the bands of the oxide spectrum broke up into masses of fine lines, exactly like those of the iodine vapour absorption-spectrum; and this remarkable resemblance was rendered still more striking by the appearance of a beat like that shown by iodine.

En outre, tous les métaux que le sodium chasse de leurs combinaisons doivent aussi y exister à l'état de liberté.

"Les nouveaux spectres que j'ai fait connaître pourront conduire à constater dans l'atmosphère solaire la présence du chlore, du brome, de l'iode, du phosphore, etc.

"D'un autre côté, de l'absence des raies d'un métal dans le spectre solaire on ne saurait conclure celle du métal lui-même dans l'atmosphère du soleil; il peut, en effet, s'y trouver des métaux, le lithium, par exemple, qui y sont engagés dans des combinaisons qui ne donnent pas de spectre."

In the former communication I have given, I trust, the true explanation of the absence of certain lines from the solar spectrum; and I think in what has gone before there is ample evidence that the explanation advanced by MITSCHERLICH is absolutely untenable; for at the temperature of the sun, which is high enough to allow hydrogen and even sodium to exist uncombined and in a state of incandescence above the photosphere, there would be heat enough to dissociate compounds, and therefore to cause the longest lines, at all events, of the metalloids to be visible even if they existed in combination as a rule, but former observers have recorded* no trace of any metalloids in the solar spectrum.

As further evidence that there is no chemical combination whatever in the photosphere, the structure of the spectrum may be also instanced; it certainly would be very different from what it is, did compounds exist in the solar atmosphere; the least refrangible end of the spectrum would, I hold, be the more, instead of the less complex; and although Professor YOUNG has recently recorded in the spectrum of a sun-spot certain appearances which might be imagined to favour the idea of the existence of compounds in the comparatively cold downrush into a spot, the general facts, to say the least, seem to point the other way, and in all my observations of sun-spots I have never seen anything approaching to the appearance put on by a compound spectrum.

On this I would also remark that with our present knowledge it is not difficult to gather from Father SECCHI's observations on stellar spectra, that if the atmosphere of a star contains compound molecules, they at once make themselves very obviously visible. Several stars, the spectra of which have been mapped by him, have undoubtedly, in my opinion, atmospheres containing compound molecules; and it may be that the phenomena of variable stars may be connected with a delicate state of equilibrium in the temperature, so that at one time we get the feeble line-absorption of the *dissociated*, and at another the strong band-absorption of the *associated* elements in their atmospheres†. Father SECCHI's idea that we have in such stars a prevalence of spot-spectrum‡, will, I think, not hold; but this point, which is one of extreme interest, I propose to dwell on at greater length in a future communication. In the mean time I may remark that I am inclined to attribute spots more to an accumulation of absorbing material *at a greater pressure* than to a similar accumulation *at a lower temperature*.

---

* ÅNGSTRÖM, 'Recherches sur le Spectre Solaire,' p. 37.

† I find that in this conclusion, drawn from my long and short line observations, I have been anticipated by ÅNGSTRÖM, who reasoned from less precise data, *op. cit.* p. 39.—Note added, January 21, 1874, J. N. L.

‡ SECCHI, 'Le Soleil,' p. 288 *et seq.*

II. MECHANICAL MIXTURES.

The mechanical mixtures experimented on in continuation of the researches referred to in my previous communication were prepared in the following manner.

Method employed in preparing mixtures.

A quantity of the larger constituent, generally from five to ten grammes, was weighed out, the weighing being accurate to the fraction of a milligramme; and the requisite quantity of the smaller constituent was calculated to give, when combined, a mixture of a definite percentage composition by weight (this being more easily obtainable than a percentage composition by volume).

The quantities generally chosen were 10, 5, 1, and 0·1 per cent.

In a few cases with metals known to have very delicate spectral reactions a mixture of 0·01 per cent. was prepared.

The larger constituent was then introduced into a small crucible (the bowl of a common clay tobacco-pipe). A tube conveying a stream of pure dry hydrogen was introduced into the mouth of the crucible, and the metal heated by a Bunsen burner.

As soon as it was melted, the metal, the spectrum of which was to be examined, was introduced in fragments, the hydrogen stream being kept up, and the heat raised if necessary until the last added metal had melted. When this had taken place, the fused mixture was agitated by rapidly shaking the crucible, or by causing the hydrogen to bubble through the melted mass.

When the mixing was judged to be complete, the mass was poured out. On cooling, a point was cut from it and placed in the spark-stand, the opposite pole being made of the metal which constituted the bulk of the mixture. Thus an alloy of 90 parts tin and 10 parts cadmium would have a tin pole opposite, and one of 90 parts lead and 10 zinc a lead pole, and so on.

It is important that each electrode of a mixture should have its corresponding electrode of the pure metal which exists in the greatest quantity in the mixture, as when the spectrum is observed the long and short lines of this constituent are seen stretching from top to bottom of the spectrum, the longest lines being continuous across, while the lines of the smaller constituent are seen *only* at the top or bottom of the spectrum, according to the place occupied by the mixture in the spark-stand.

Observations.

The observations thus made have been recorded in the accompanying maps* in the following manner:—First the pure spectrum of the smallest constituent has been observed, and the lines laid down from THALÉN's map generally.

The mixture containing the greatest percentage of the substance whose spectrum is to be studied is then inserted in the spark-stand with its opposite electrode of the substance with which it is mixed, and the spectrum observed. This process is repeated until the lowest percentage is reached.

---

* These maps were exhibited to the Society, but they have not been engraved.

In the maps the spectrum of the pure vapour is shown below, the spectra of the mixtures above, the highest spectrum being that of the mechanical mixture containing the smallest percentage.

The series mapped are as follows:—

Sn + Cd	percentages of	Cd	10,	5,	1,	0·15
Pb + Zn	„	Zn	10,	5,	1,	0·1
Pb + Mg	„	Mg	10,	1,	0·1,	0·01

I may remark that these substances were used in consequence of their low fluid temperatures and of the consequent ease with which the mixtures could be made with the arrangements at my disposal.

An inspection of the maps will render any long verbal statement of the results obtained superfluous. I may, however, remark that although we have here the germs of a quantitative spectrum-analysis, the germs only are present, because from the existence of several "critical points"*, and great variations due to causes which have not yet been investigated, the results thus obtained are not sufficiently close or constant for practical application.

Further researches, however, have shown me that, by discarding altogether this method of eliminating lines from the spectrum and adopting a different procedure, it is possible by means of spectrum-analysis to make quantitative determinations of certain mixtures with almost if not quite as great accuracy as that generally obtained by the methods in use.

As these researches are still incomplete, I shall defer an account of them and the process adopted till a future occasion.

Application of these observations to the Solar Spectrum.

Let it be assumed for a moment that subsequent investigations may justify us in applying these considerations to the composition of the reversing layer in the sun's atmosphere, and suppose it to be composed of a mixture of zinc and lead vapours.

The percentage of zinc indicated by the number of lines actually known to be reversed in the solar spectrum would certainly be between one and five per cent.

Similarly, the percentage of sodium would be 100 per cent., of magnesium 100 per cent. at the maximum sun-spot period, a little less at other times; the percentage of iron always something less than 100 per cent., and so on. Adding these percentages together, we get an apparently impossible percentage composition of the reversing layer. But here another set of considerations comes in. In each case the percentage composition has been assumed to be determined by the lines omitted from the spectrum observed at atmospheric pressure—a pressure accidental to this planet.

---

* For instance, in the cadmium experiments but little difference occurs between 10 per cent. and 5 per cent. In the case of zinc between 10 per cent. and 5 per cent. only a very small change occurs. In the case of magnesium only two lines are lost between 100 and 10 per cent.

It follows, however, from what has gone before, that the number of lines in a spectrum increases as the molecular distance is diminished within the range of atmospheric pressure; and there is no doubt whatever that this will go on with greater pressures until a continuous spectrum is reached, as in FRANKLAND'S classical experiment with hydrogen, in which the lines *broadened*—a peculiarity confined, so far as I know, to that spectrum.

If this be so, with *increased* pressure we shall get *reduced* percentages; and some day we possibly shall be able to largely increase our present knowledge by observing the pressure at which, with the increased number of spectral lines in the pure vapours known to be in the sun, the percentages of the known solar elements, determined by their reversed lines, will together make up 100 or thereabouts. It is clear, however, already that a pressure of several earth atmospheres would be required.

Such an inquiry might not so much make us familiar with the existence of new elements in the reversing layer as it would enable us to allocate the unnamed lines of the spectrum to those already known to exist there; and it may also be remarked that now the absence of any element from the sun is much more easily determined than before, as its longest line only need be considered. If *that* is not reversed the inquiry need be carried no further, for all other lines will certainly be absent. I do not wish to imply that a *trace* of an element can be detected in this way, my experiments rather tend in the other direction; besides which it must not be forgotten that we have bright lines in the solar spectrum itself, and that in the chromosphere I have recorded bright lines; and Professor YOUNG has recently recorded more in some observations, to which I shall take a future opportunity of referring.

It is a pleasing duty to me to again take an opportunity of expressing my obligations to Mr. FRISWELL for the valuable assistance he has afforded me in these inquiries. All the maps have been constructed by him.

I have also to express my thanks to G. GORE, Esq., of Birmingham, who supplied me with the fluorides used in the experiments, and to J. MELLOR, Esq., of the Magnesium Metal Works, Salford, for a present of a large quantity of magnesium, potassium, and other metals, which have also been used in these inquiries; they were sent anonymously, but I have learnt the donor's name from Professor ROSCOE.

Explanation of the Plates.

PLATE LI.

Upper Half.

Spectra of strontium salts in air with low-tension spark.

A, spectrum of $\mathrm{Sr\,I_2}$.
B, ,, ,, $\mathrm{Sr\,Br_2}$.
C, ,, ,, $\mathrm{Sr\,Cl_2}$.
D, ,, ,, $\mathrm{Sr\,F_2}$.
E, ,, ,, metallic strontium.

Notes.—Some of the lines in the red in the spectrum of strontic fluoride are seen, but the "structure" of the compound spectrum renders it difficult to decide which.

The structure (for the first three salts) is at first exceedingly brilliant and varies with each salt, but after a time it gets dimmer and is the same for all salts.

The brilliant compound spectrum renders the presence of the lines at W. L. 5970·5 and 5850·0 in the salts very doubtful.

The line 4226·3 has since been proved to belong to calcium.

The line 4161·0 is always very faint.

Lower Half.

Spectra of lead salts in air with low-tension spark.

A, spectrum of $\mathrm{Pb\,I_2}$.
B, ,, ,, $\mathrm{Pb\,Br_2}$.
C, ,, ,, $\mathrm{Pb\,Cl_2}$.
D, ,, ,, $\mathrm{Pb\,F_2}$.
E, ,, ,, metallic lead.

Notes.—The line 6452·0 was very faint and difficult of observation in $\mathrm{Pb\,F_2}$.

The line 5163·0 is coincident with an air line, and its length is uncertain in the metallic spectrum, though it is brilliant. It is, however, long in the salts.

The lines 4386·5 and 4246·0 only appear for a short time in the spectrum of $\mathrm{Pb\,F_2}$, though the time is longer than in the other salts. In $\mathrm{Pb\,I_2}$ they flash in and instantly vanish; in $\mathrm{Pb\,Cl_2}$ they vanish nearly as quickly.

The line 4062·5 is faint; it is probably not a lead line.

4058·0 is the longest line.

PLATE LII.

UPPER HALF.

Spectra of strontium salts in hydrogen with low-tension spark.

A, spectrum of SrI_2.
B, ,, ,, $SrBr_2$.
C, ,, ,, $SrCl_2$.
D, ,, ,, metallic strontium.

Notes.—The lines in the red have been omitted, as they are difficult of observation, and the point is proved by the more refrangible lines. The bands are *approximately* laid down on the wave-length scale from readings of the scale of the Steinheil spectroscope.

LOWER HALF.

Spectrum of the oxide of aluminium compared with the spectrum of the pure metal.

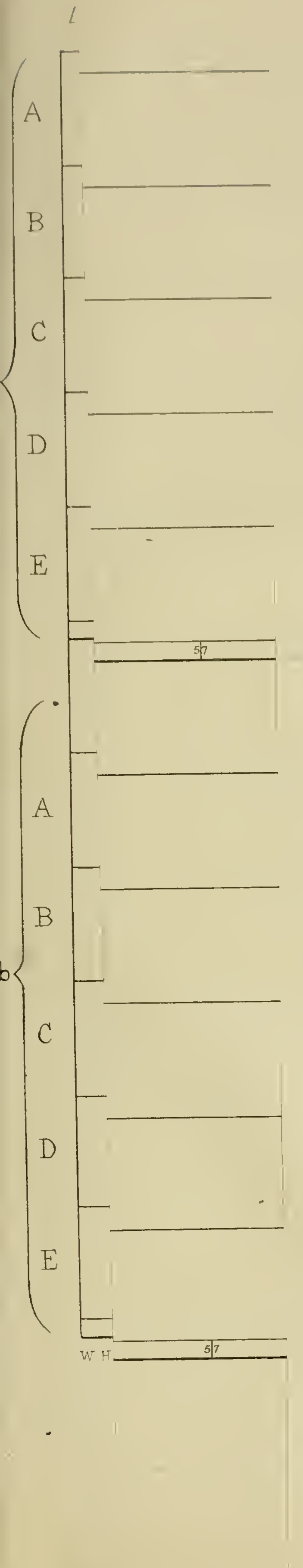
A, spectrum of aluminium oxide.
B, ,, ,, aluminium.

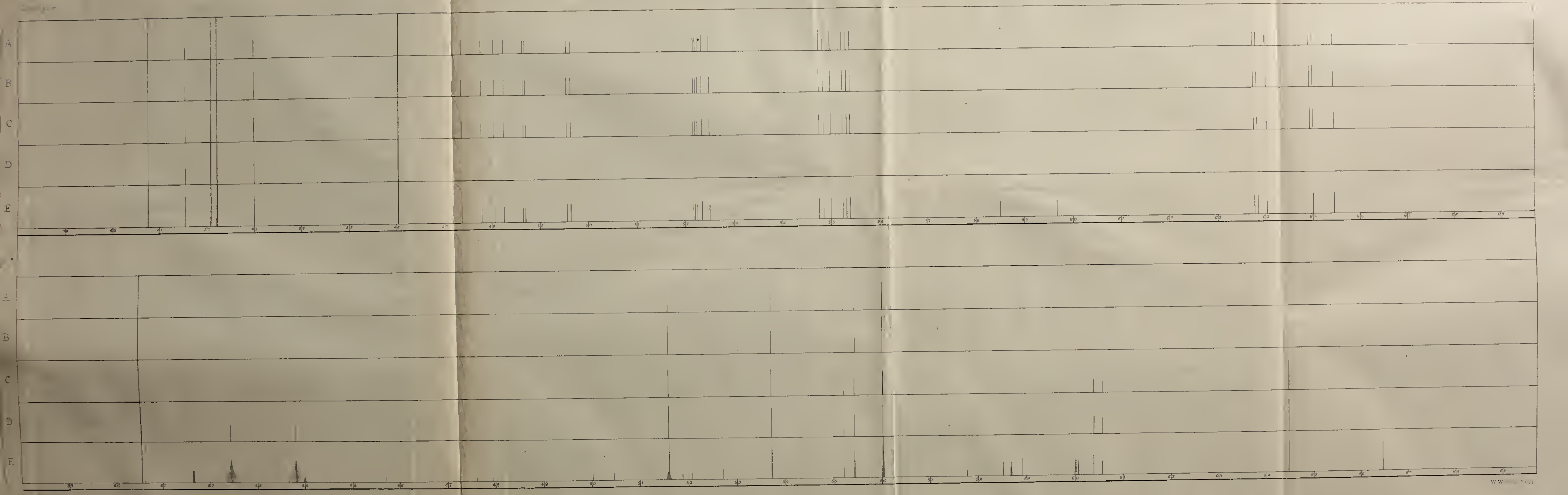
Notes.—The lines at W. L. 6371·0 and 6344·5 are not shown; they have not been identified though seen by THALÉN.

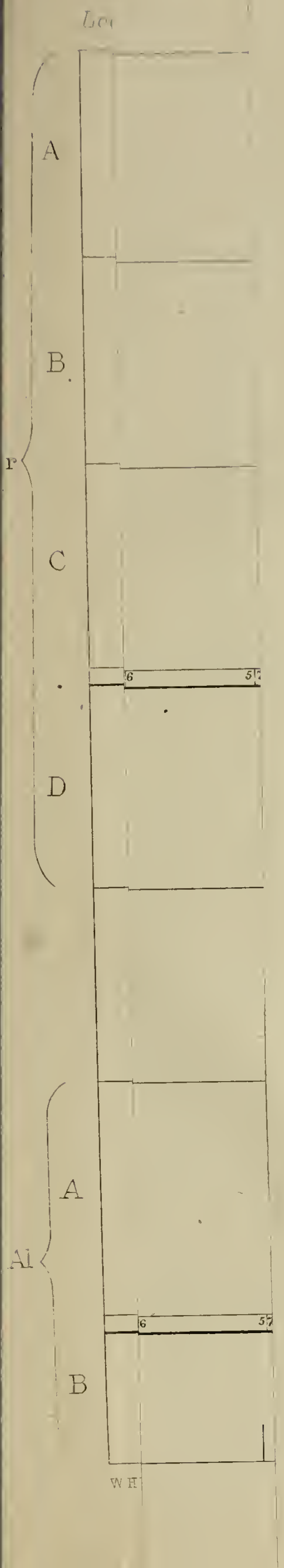
The spectrum A disappears in hydrogen.

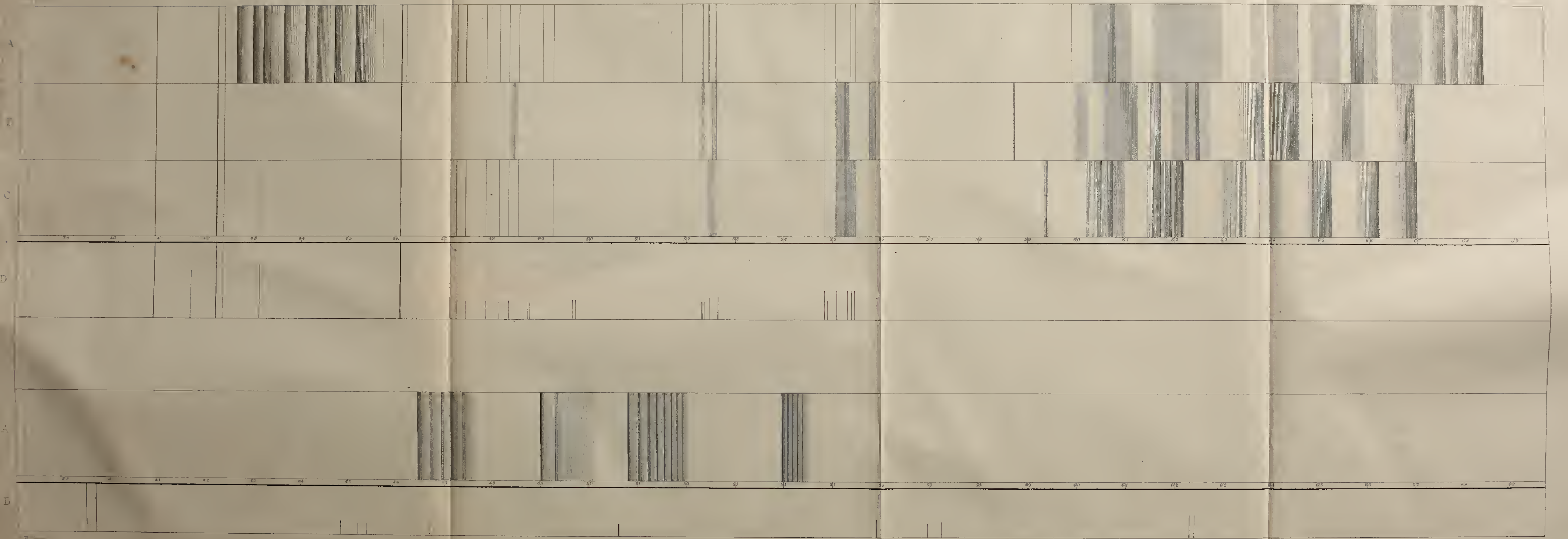
In air, with a low-tension spark, none of the metallic lines are seen, indicating that the oxide (Al_2O_3?) is not at all dissociated.

The oxide spectrum is laid down on a wave-length scale from careful approximations to the lines of air, copper, and zinc.


l
A
B
C
D
E
57
A
B
C
D
E
b
W H
57


A
B
C
D
E
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69


Lc
A
B
r
C
6
5
D
A
Al
6
5
B
W H


A
B
C
D
E
D

INDEX

TO THE

PHILOSOPHICAL TRANSACTIONS

FOR THE YEAR 1873.

A.

Airy (Sir G. B.). Magnetical Observations in the Britannia and Conway Tubular Iron Bridges, 331.

Amblygonite, 574.

Ammonia, condensation of, by ammonia nitrate, 359.

Animal remains found in Brixham Cave, 499.

B.

Bakerian Lecture, 1872.—On the Structure and Development of the Skull in the Salmon, 95 (see Parker).

Bakerian Lecture, 1873.—On the Radiation of Heat from the Moon, &c., 587 (see Rosse, Earl of).

Barometrical variations, diurnal, in connexion with those of the wind, 1.

Belgium, magnetic survey of, 341.

Bristow (H. W.). Notes of his Survey of the Brixham Cave, 496.

Brixham Cave, report of the exploration of, 471 (see Prestwich).

Busk (G.). Report of the Animal Remains of the Brixham Cave, 499.

C.

Cave, exploration of Brixham, 471.

Cayley (A.). On Curvature and Orthogonal Surfaces, 229.—Conormal correspondence of vicinal surfaces, 237; condition that two surfaces may belong to an orthogonal system, 245; that a family of surfaces may belong to an orthogonal system, 248.

Challenger expedition, remarkable crustacean obtained in the, 629.

Chambers (F.). The Diurnal Variations of the Wind and Barometric Pressure at Bombay, 1.

Clarke (A. R.). Results of the Comparisons of the Standards of Length of England, Austria, Spain, United States, Cape of Good Hope, and of a second Russian Standard, made at the Ordnance Survey Office, Southampton, 445.

Contraction of slags &c. in cooling, 191.

Crookes (W.). Researches on the Atomic Weight of Thallium, 277 (for contents see p. 277).
Crushing of rocks, experiments on heat developed by the, 180.
Cubit, value of the ancient, 445.

D.

Des Cloizeaux (A. O.). On a new Locality of Amblygonite, and on Montebrasite, a new Hydrated Aluminium and Lithium Phosphate, 573.—Amblygonite, 574; Montebrasite, 582; Wavellite, 585.
Dictyoxylon, 377.
Diplopus, 41 (see Kowalevsky).
Divers (E.). On the Union of Ammonia Nitrate with Ammonia, 359.

E.

Eclipse of Moon, comparison of Moon's Heat and Light during, 619.
Electrostatic units, number of, in electromagnetic unit, 409.
Evans (J.). Remarks on the Worked Flints found in Brixham Cave, 549.

F.

Flint implements of Brixham Cave, 549.
Fossil plants of the Coal-measures, 377.

H.

Heterangium, 377.
Hyopotamidæ, osteology of, 19.

J.

James (Sir H.). Notes on the Greek and Egyptian Measures of Length, 445.

K.

Kowalevsky (W.). On the Osteology of the *Hyopotamidæ,* 19.—Introduction, 19; bones of skeleton, 30; general considerations on the carpal, tarsal, &c. bones in Paridigitata, 41; carpus of Hyopotamus, 45; tarsus of Diplopus and Hyopotamus, 52; metacarpus and metatarsus, 80; phalanges, 88; explanation of plates, 90.

L.

Lockyer (J. N.). Researches in Spectrum-Analysis in connexion with the Spectrum of the Sun.—No. I., 253.
——— Researches in Spectrum-Analysis in connexion with the Spectrum of the Sun.—No. II., 639 (for contents see p. 639).
Lyginodendron, 377.

M.

M'Kichan (D.). Determination of the Number of Electrostatic Units in the Electromagnetic Unit made in the Physical Laboratory of Glasgow University, 409.

Magnetic Survey of Belgium in 1871, 341.

Magnetical observations in tubular iron bridges, 331.

Mallet (R.). Volcanic Energy: an attempt to develop its true Origin and Cosmical Relations, 147.—Heat developed by the crushing of rocks, 180; contraction of slags &c. in cooling, 191; appendix, thermal springs, 222; heat and work from quartz-crushing, 223.

Metals, bright lines in spectra of, 266.

Montebrasite, 582.

Moon, radiation of heat from the, 587.

Muscles, minute structure of, in the water-beetle, 429.

O.

Orthogonal surfaces, 229.

P.

Paridigitata, 41 (see Kowalevsky).

Parker (W. K.). The Bakerian Lecture.—On the Structure and Development of the Skull in the Salmon, 95.—Introduction, 95; eighth stage, adult skull, 98; first stage, embryos, 112; second, unhatched, 120; third, still unhatched, 122; fourth, newly hatched, 125; fifth, fry of second week, 127; sixth stage, sixth week, 135; seventh, of first summer, 137; explanation of plates, 142.

Pengelly (W.). Report on the Structure and Contents of Brixham Cave, 483.

Perry (S. J.). Magnetic Survey of Belgium in 1871, 341.

Prestwich (J.). Report on the Exploration of Brixham Cave, conducted by a Committee of the Geological Society, and under the superintendence of Wm. Pengelly, Esq., aided by a local Committee; with Descriptions of the Animal Remains by George Busk, Esq., and of the Flint Implements by John Evans, Esq., 471 (for contents see p. 471).

R.

Rosse (Earl of). The Bakerian Lecture.—On the Radiation of Heat from the Moon, the Law of its Absorption by our Atmosphere, and its Variation in Amount with her Phases, 587.—Determination of the law of extinction of the moon's radiant heat in our atmosphere, 592; comparison of the reducing curve in zenith-distance with Laplace's law, 616; simultaneous observations of the moon's heat and light during the eclipse of November 14th, 1872, 619; comparison with Zöllner's results, 620; moon's heat compared with that from a terrestrial source, 621; appendix, 624.

S.

Salmon, development of the skull in the, 95.

Schäfer (A.). On the Minute Structure of the Leg-muscles of the Water-beetle, 429.

Skull, development of, in Salmon, 95.

Spectra of sun and stars, 253, 652, 655; *of metals*, 266; *of metallic compounds*, 641; *of metalloids*, 652; *of alloys*, 654.

Standards of length, comparison of national, 445; table of results, 469.

Sun, spectrum of the, 253, 639.

T.

Thallium, atomic weight of, 277.

Thaumops pellucida, 629, 637.

V.

Volcanoes, theory of, 147.

W.

Wavellite, 585.

Willemoës-Suhm (R. von). On a new Genus of Amphipod Crustaceans, 629.—Appendix. On the Male and Structure of *Thaumops pellucida*, 637.

Williamson (W. C.). On the Organization of the Fossil Plants of the Coal-measures.—Part IV. *Dictyoxylon, Lyginodendron*, and *Heterangium*, 377.

Wind, diurnal variations of, in connexion with those of the barometer, 1.

LONDON:
PRINTED BY TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET.

UNIVERSITY OF ILLINOIS-URBANA
3 0112 060765861